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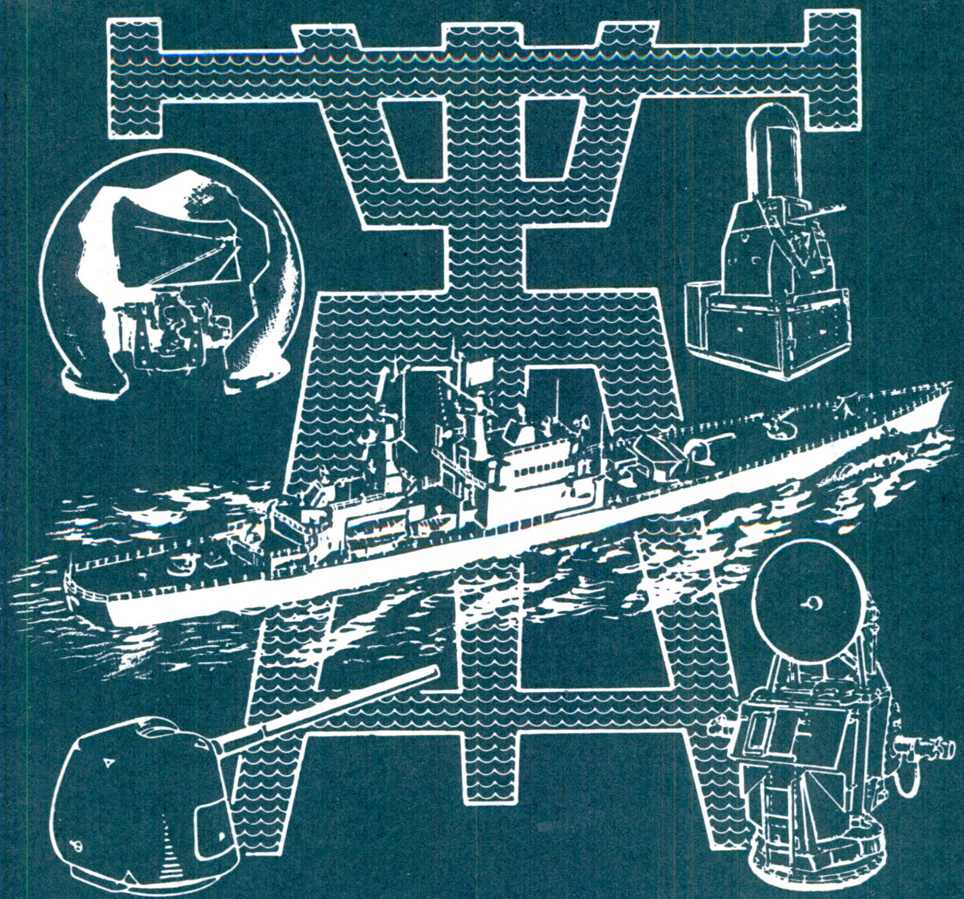

FIRE CONTROL TECHNICIAN G 3 & 2

NAVAL EDUCATION AND TRAINING COMMAND
RATE TRAINING MANUAL AND NONRESIDENT CAREER COURSE
NAVEDTRA 10207-B

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STACKS

Although the words "he", "him", and "his", are used sparingly in this manual to enhance communication, they are not intended to be gender driven nor to affront or discriminate against anyone reading *Fire Control Technician (G) 3 & 2*, NAVEDTRA 10207-B.

Naval Education And Training Program Development Center

FIRE CONTROL TECHNICIAN
G 3 & 2

NAVEDTRA 10207-B

DEPARTMENT OF THE NAVY
CHIEF OF NAVAL EDUC AND TNG

1981 Edition Prepared by
FTCS Allen R. Bergeron and FTMC Frank E. Sloan

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PREFACE

This Rate Training Manual and Nonresident Career Course (RTM/NRCC), *Fire Control Technician (G) 3 & 2,* NAVEDTRA 10207-B, is intended to provide enlisted personnel with background information necessary for advancement to the rates of Fire Control Technician (G) Third and Second Class. This includes information on gun weapon control systems, gun system testing and safety, fire control radars, support systems, battery alignment, administration, and general maintenance.

Designed for individual study vice formal classroom instruction, the RTM provides subject matter that relates directly to the Occupational Standards of the Fire Control Technician (G) 3 & 2 rates. The NRCC, located after the index of this book, provides the usual way of satisfying the requirements for completing the RTM. It consists of a set of assignments which include learning objectives and supporting questions designed to help students complete the RTM. You may find it beneficial to browse the entire training package and to read the front matter to the NRCC before you begin serious study.

This training manual and nonresident career course was prepared by the Naval Education and Training Program Development Center, Pensacola, Florida, for the Chief of Naval Education and Training. The following commands provided reviews during the preparation of the manual: Naval Sea Systems Command, Washington, D.C.; Service School Command, Great Lakes, Illinois; Naval Submarine School, Groton, Connecticut; Navy Fleet Ballistic Missile Submarine Training Center, Charleston, South Carolina; USS *Dale* (CG-19); USS *Sellers* DDG-11; USS *Spruance* DD-963; and USS *MacDonough* DDG-39.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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CHAPTER 1

FIRE CONTROL TECHNICIAN GUN RATING

INTRODUCTION

This rate training manual (RTM) has been prepared to help you meet the occupational standards that apply to the rate of Fire Control Technician G 3 & 2. The guidelines for preparing this RTM are the occupational standards located in NAVPERS 18068 (latest edition). By satisfactorily completing this course and the requirements stated in the *Bibliography for Advancement Study,* NAVEDTRA 10052 (latest edition), you will have the technical background information necessary to assist you in passing the advancement examination and helping you to advance to the next higher paygrade.

FIRE CONTROL TECHNICIAN GUN RATING

The purpose of this chapter is to introduce you to the rating for which you have been selected. The term "fire control" means the directing of various weapons so that they will hit the desired target. As you learn about fire control, you will realize that the Navy is only as strong as its fire power and in order for its fire power to be effective, it must be accurately controlled. That is where you, as a fire control technician, play a vital part in making your ship an effective weapon against enemy ships, planes, and shore installations. It will be your job to operate and maintain the many complex devices used in your ship's various fire control systems.

DUTIES OF AN FTG

All ships include, as one of their main departments, a Weapons Department. On some ships of special type, whose primary mission is something other than ordnance, this department may be subordinated to become part of the Deck Department. On combat ships, an FT is most likely to be assigned to the Weapons Department. The Weapons Department is a major, independent department of the ship's organization. The department is headed by a Weapons Officer who is assisted by a First Lieutenant. The First Lieutenant has direct responsibility for all deck equipment and seamanship operations. The Weapons Department, under these two officers, is responsible for the operation and maintenance of all weapons, weapons systems components, and deck gear. This is the department to which the FT is regularly assigned.

Your duties may be outlined briefly as follows:

1. You must be able to perform the general procedures necessary to operate and stand watch on all fire control equipment and related electronic units in your charge.
2. You must be able to maintain, test, align, calibrate, and troubleshoot all of this equipment. To perform these duties, you must be able to:
    a. Perform all periodic cleaning, lubrication, and testing required by the equipment placed in your charge
    b. Use all tools and instruments, mechanical and electrical, necessary for the performance of your duties
    c. Read and use mechanical drawings, blueprints, schematics, and wiring layout diagrams
    d. Locate troubles and make necessary repairs

3. You must be able to go through the procedures necessary to requisition and stow all parts and supplies required in your work. You must also be able to prepare work requests as needed.

4. You must be able to maintain fire control records according to an established format.

5. You must be able to boresight guns and align weapon systems.

6. You may be called upon to inspect and maintain optical instruments associated with fire control equipment.

7. You must be able, under supervision, to install fire control equipment and accessories and to make certain field changes of a limited nature.

Do not let this list of duties throw you. You will not have them piled on your shoulders all at once. When you get aboard ship, you will find that there are already FTs aboard who have been doing this job for some time. They will help you get started on the right foot.

Now that you have made a quick survey of your duties, let's see how they fit into the larger picture of fire control duty afloat. You probably have many questions concerning the type of ship on which you will be stationed, the number of hours a day you will be on duty, whether you will be working by yourself or as a member of a crew, what your combat duties will be, what your maintenance duties will be, etc.

The information which follows will answer most of these questions for you.

Watches

A ship at sea does not shut down for the night. Someone is always on watch aboard your ship. The various lookout stations are always manned. In short, every vital service on board a ship must have someone on watch at all times. In order to maintain this 24-hour vigilance, the watch system was established long ago on board all ships. The various watches are as follows:

0000 - 0400	Mid-watch
0400 - 0800	Morning watch
0800 - 1200	Forenoon watch
1200 - 1600	Afternoon watch
1600 - 1800	First Dog watch
1800 - 2000	Second Dog watch
2000 - 2400	Evening watch

The two "Dog" watches are shortened, or dogged, to give those on duty a chance to eat their evening meal and share in the recreation period. Your place in the ship's organization and your stations for the various shipboard drills will be listed on the Watch Quarter and Station Bill and it will be posted on your divisional bulletin board. In addition, you may be given a "billet slip," which will give you the details of your assignments.

When a ship is at sea the watches are arranged as described above and are called cruising watches. Under war conditions or on maneuvers there are four conditions of readiness for battle or simulated battle conditions. These are:

Condition IV—The condition IV underway watch is that condition of readiness that provides the optimum peacetime cruising watch, consisting of adequately qualified personnel for the safe and efficient operation of the ship, while permitting the best economy of personnel in assignment to watches. It is the normal peacetime cruising condition. No weapon batteries are manned. Complete surface lookout coverage is provided. Air lookouts are on duty when flight operations are in progress in the vicinity.

Condition III—There is possibility of attack at any time. Watch conditions are four hours on and eight hours off.

Condition II—There is possibility of attack at any time. Watch conditions are four hours on and four hours off.

Condition I—This is the same condition as general quarters. Everyone is at a designated battle station and attack is imminent. All equipment is tested and ready for action.

General quarters (GQ) is sounded whenever there is danger of immediate attack, whenever a lookout spots a periscope, when radar detects an unidentified plane, or when sonar detects a submarine. Condition I also exists when the ship has entered waters under surveillance by the enemy or under any other conditions where there is known danger of attack. The announcement of GQ will differ according to ship; but, no matter what type of ship you are on, it will be unmistakable. GQ may be announced by the continuous sounding of a bell, a siren, or a horn; or by the words "general quarters" or a bugle call over the loud speaker system. When you hear GQ, stop whatever you are doing and go to your assigned battle station.

Maintenance Duties

If you have ever taken care of an automobile, a bicycle, or a plain, old-fashioned adding machine without any electronic trimmings, you must know that it is much easier to keep a machine properly serviced than to repair a breakdown. Take the case of an automobile. It is easier to keep the air in a tire at the proper pressure than to fix a blowout on a busy highway. It is easier to keep the crankcase oil at the correct level than to have to replace the bearings. It may take only 2 minutes a week to keep the radiator full, but it may take 10 hours and many dollars to repair the damage caused by overheating. For the same reasons, you have to inspect the brakes, clean and adjust the spark plugs, and adjust the distributor points. By taking time to do this maintenance work, you save yourself the much more extensive work and expense that would be necessary in the event of a breakdown. In addition, by driving a safe car on a fast highway, you may be saving the lives of other people or your own life.

It is the same story with all types of electrical and electronic equipment. If you average out all the maintenance work that should be done, you will find that it requires only a relatively small part of each day. By doing this very modest amount of work, you may avoid a breakdown that would occupy you for many hours or perhaps necessitate calling on an individual in some other rating to put your equipment in shape again. Finally, a little maintenance work every day is a low price to pay for insurance against a breakdown at a crucial moment in combat. The Navy must always be prepared for an emergency.

The complete weapons system of a ship contains many complex units and any one of these units may contain a vast number of electrical and mechanical components. Although many of the parts may appear to be quite delicate in construction, you will learn that they have been designed to have a very long life expectancy. Under ideal conditions, this equipment could operate for long periods with no maintenance other than the replacement of mechanical parts which are subject to wear. You must be prepared, however, to find that conditions aboard ship are far from ideal for electronic equipment.

Electrical and electronic equipment aboard ship is exposed to mechanical shocks, vibration, dampness, salt action, wide variations in temperature, and possible mishandling by inexperienced personnel. These conditions cause breakage, loosening of connections, excessive wear, corrosion, loss of adjustment, and breakdown of insulation. It is the purpose of maintenance to keep this kind of wear and tear to a minimum and, where it does occur, to detect and correct it before serious damage develops.

You can combat the conditions described above by cleaning, lubrication, inspection, and periodic performance testing. You probably already understand the principles of lubricating surfaces which move against each other. The details as to what and when to lubricate and the correct oils and greases to be used are explained in equipment publications.

Cleaning is of particular importance with reference to the effects of dampness and salt action. Dirt absorbs moisture, and moisture aboard ship is likely to contain particles of salt. Salt water has a corrosive action on metal surfaces. Moral: It is important to keep your equipment both dry and clean.

Finally, you will find that conditions affecting maintenance vary in different locations on the earth. This means you will have to adjust your schedules for lubrication and cleaning.

Now that you have been introduced to the main duties of an FT, let's consider some of the secondary aspects of your job. These secondary requirements make it possible for you to discharge your major responsibilities more effectively.

It should be obvious that you can not make repairs, however minor, or do any of the necessary servicing of your equipment unless you have the right supplies and spare parts on hand. It should also be evident, that in order to have the right things on hand at the right time, you must know what to order, when and how to order, and also how to store the various supplies so there will be no loss, breakage, or other deterioration. To some people, the standardization of procedures for things of this nature is always irksome. It seems to them a lot of unnecessary paperwork to have to fill out certain forms in the required manner, with a specified number of copies, and to obtain several different signatures of approval. To anyone who gives it a little thought, however, it should be obvious that the routines are necessary and desirable. In no other way could the large-scale distribution of parts and supplies be directed effectively.

In the same way, certain standard procedures must be carried out in order to get work done by a member of some other rating. These procedures have been devised and systematized in order to accomplish various tasks efficiently. It might seem simpler for an FT merely to shout to an EM, "Drop around when you're not busy and take a look at this motor; it isn't working correctly." You will find, however, that it gets you further to notify your supervisor in the approved manner when you have a repair problem beyond your facilities.

When changes have to be made to existing electronic units associated with fire control equipment, or when new equipment is to be installed on board a ship, the work is usually done at a naval base or by a special team of technicians sent on board for that particular purpose. Sometimes, however, the work is simple enough to be done by the ship's technician force. At other times, although the work may be quite complicated, it is of such importance that there must be no delay and the job is also assigned to the ship's force.

To alter equipment or to make new installations, you will have to know how to read and use mechanical drawings, blueprints, schematics, and wiring layout diagrams. You also will have to know how to use various tools and all types of test equipment. This type of work will be done under the direction and supervision of a petty officer; but, you will be expected to perform your share of the work.

If all problems of maintenance could be solved by proficient lubrication and cleaning, you would only have to work out the best possible schedule for giving your equipment this care and then follow the schedule. However, since this will not do the whole job, you must also watch for troubles which have not or cannot be prevented by cleaning and lubrication.

Periodic inspection and performance testing will help locate troubles that are in the early stages of development and have not caused a breakdown.

Periodic inspection should include examination of tube sockets, electrical connections, switch contacts, cable runs, and mechanical components. Any sign of wear, cracking of insulation, corrosion, or breakage should be corrected immediately by repair or replacement of the affected parts.

Performance testing locates developing troubles which cannot be found by visual or resistance checks. Definite standards of transmitter power, receiver sensitivity, and frequency range must be met. By putting your equipment through standard tests, you can tell whether or not its operation is satisfactory in all respects. A systematic schedule for such tests, inspections, and checks as have been described, calls for certain routines to be followed daily, weekly, monthly, quarterly, or annually. When you find that something is not performing up to standard, you will go through regular troubleshooting procedures to locate the cause. The condition to be corrected may be a weak tube, a tuned circuit out of adjustment, or some other electrical or mechanical malfunction. You will be qualified to find and correct such conditions when you have studied the particular equipment for your rating.

GUN WEAPON SYSTEM OVERVIEW

Gun weapons systems have played and continue to play an important role in achieving battle victories, both on land and at sea. In addition to their destructive power against ships and aircraft, and their gunfire support role, gun weapon systems can be used to destroy enemy strongholds far inland.

Gun weapon systems are constantly changing as new technologies are applied to fire control equipment. Radars may be replaced by newer more accurate ones; computers by smaller and faster ones. Entire systems are sometimes replaced by new more efficient types. However, the basic idea of gun weapon system does not change. They all need certain components in order to operate as a complete system. Figure 1-1 shows the basic components that may be found in any of the gun weapon systems on our ships today.

The following information is a brief functional description of the components shown in figure 1-1.

DIRECTOR/ANTENNA

The function of the director/antenna is to locate the position of a target. You may think of it as the eyes of the fire control system.

There are several different fire control systems in the fleet today. Some have gun

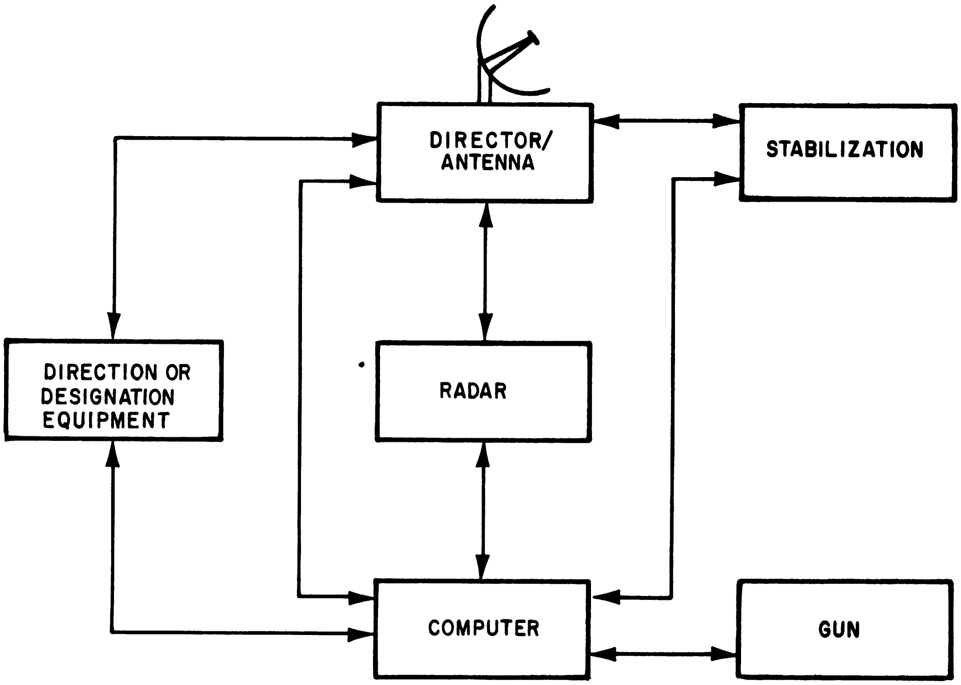

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Figure 1-1.—Typical fire control system.

directors (fig. 1-2) and others have simply antenna systems (fig. 1-3). In either case, its function is to locate the position of a target.

The director/antenna incorporates radar equipment and optical equipment, or both. It is normally located high in the superstructure of the ship to allow the greatest vision over the horizon.

RADAR

Radar uses echoes of high-frequency radio pulses to establish continuous values of target range. Bearing and elevation to the target are determined by the direction in which the radar antenna is pointing.

COMPUTER

Fire control computers are electronic or electromechanical devices into which are fed the mathematical variables in the fire control problem. They yield solutions in the form of position signals, which are required for the gun's projectile to hit the target.

STABILIZATION

Stabilization is accomplished by gyroscopic devices that maintain a reference horizontal, independent of the ship's pitch and roll, for use in solving the fire control problem. These devices are called stable elements or stable verticals.

DESIGNATION/DIRECTION EQUIPMENT

Designation or direction equipment is used to transmit target position from the ship's search radar to a fire control system.

Often, there is more than one fire control system on a ship. With the aid of designation or

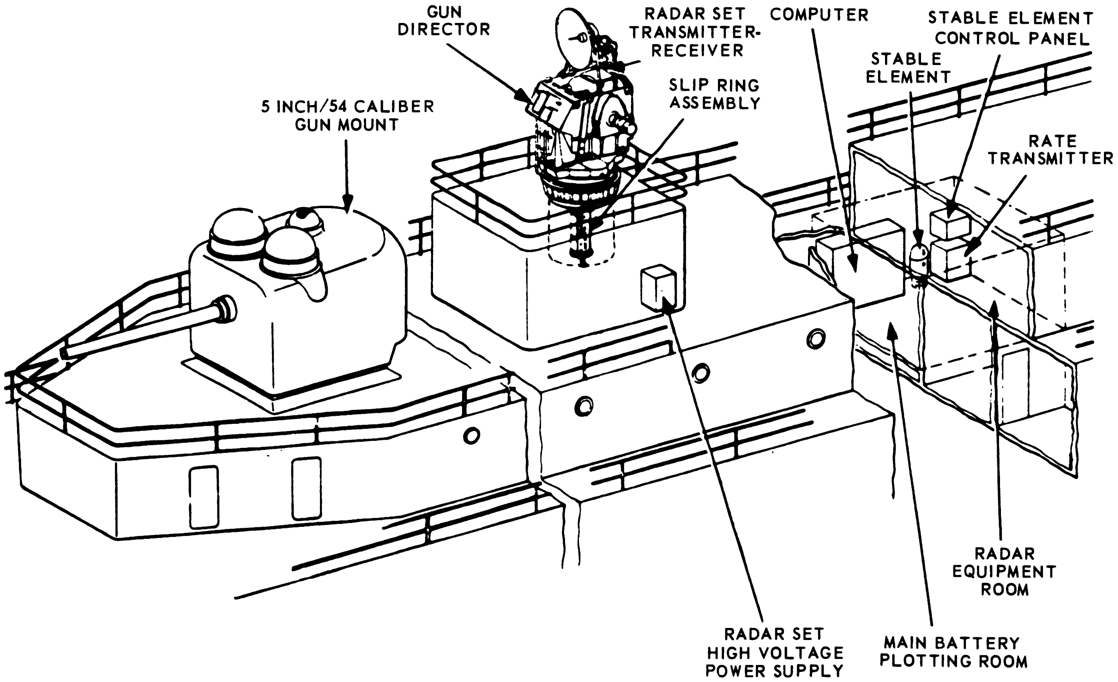
GUN DIRECTOR
RADAR SET TRANSMITTER-RECEIVER
COMPUTER
STABLE ELEMENT CONTROL PANEL
STABLE ELEMENT
SLIP RING ASSEMBLY
5 INCH/54 CALIBER GUN MOUNT
RATE TRANSMITTER
RADAR EQUIPMENT ROOM
RADAR SET HIGH VOLTAGE POWER SUPPLY
MAIN BATTERY PLOTTING ROOM

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Figure 1-2.—Arrangement of GFCS Mk 68.

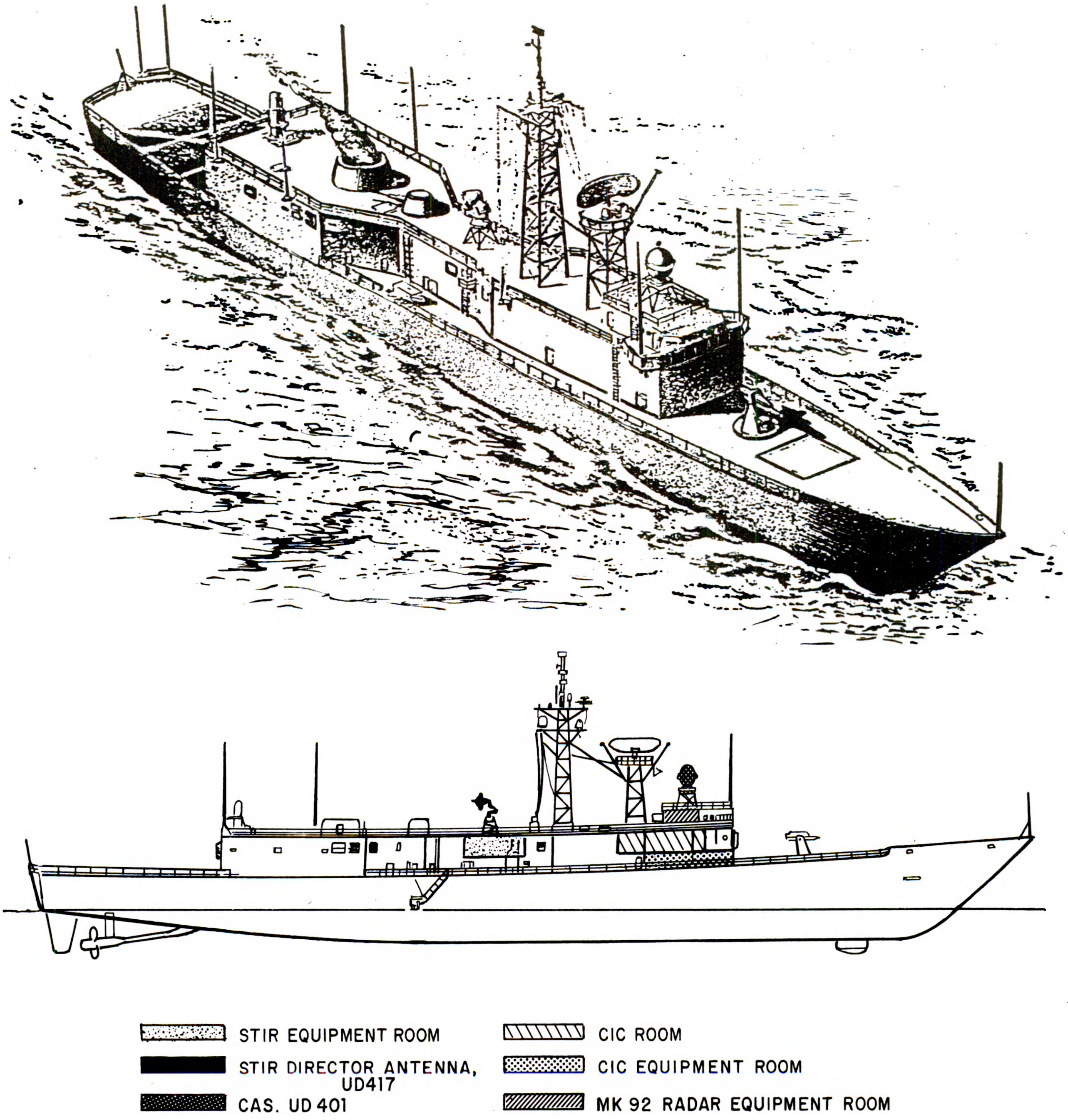

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Figure 1-3.—Typical ship installation of Fire Control System Mk 92 Mod 2.

direction equipment, multiple targets can be transmitted to the fire control systems with smooth, rapid, and accurate information.

GUN

Essentially a gun is a tube closed at one end, from which a projectile is ejected at a high speed by gases produced by a burning propellant.

As was mentioned earlier, the words "fire control" mean the directing of various weapons so that they will hit the desired target. As a fire control technician, you are not expected to perform maintenance on gun mounts. However, you should be familiar with the signal flow to the gun, since it is the business end of your fire control system.

SUMMARY

You should now have an understanding of what fire control means, and what will be expected of you as a fire control technician.

Figure 1-1 shows the basic components of a fire control system. These components will be covered in more detail in the following chapters of this rate training manual.

The field of fire control is constantly changing as new technology is applied to fire control equipment. As an FT, you have both the opportunity and responsibility to keep up with the latest advances. The Navy will provide you with numerous correspondence courses to aid in your quest for knowledge. How far you go is up to you.

CHAPTER 2

DATA TRANSMISSION

INTRODUCTION

For various reasons, components of gun fire control systems are located at many different areas throughout a ship. The higher the director, or antenna, is located, the farther it can see out on the horizon. The closer the stabilization unit is to the water line of the ship, the easier it is to correct for the ship's roll and pitch. The radar and computer are located below deck for protection from the inclement weather often encountered at sea.

All of these components of the fire control system must be made to work together. They must be controlled so that their functions complement each other. This is necessary so that the fire control problem may be solved and enemy action neutralized.

It takes a lot of information to solve the fire control problem and to enable you and your fellow technicians to control this large and complex system. Figure 2-1 shows data being sent back and forth between equipments located

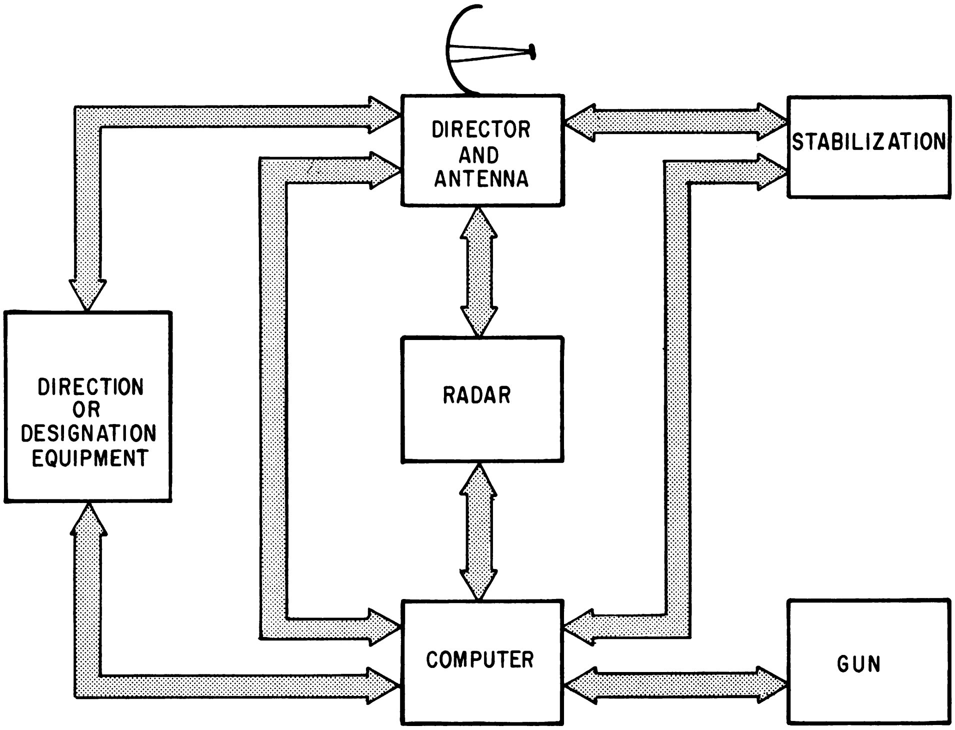

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Figure 2-1.—Data transmission.

at a distance from each other. For example, a computer needs target range from the radar and target bearing and elevation from the director. The gun needs position orders from the computer. The director or computer needs position orders from a designation source. All of these basic quantities are supplied by equipment located at distances of a few feet to possibly several hundred feet from each other. Some sort of data transmission system is needed.

FIRE CONTROL TRANSMISSION DEVICES

All data transmission systems consist basically of a signal-producing device (transmitter), a transmission medium (conductor), and a receiver (load), as shown in figure 2-2. Switches and relays, synchros, vernistats, and tachometers are devices typically used in fire control systems and will be presented in this chapter.

SWITCHES AND RELAYS

Information can be transmitted by the presence or absence of a voltage. This is the basis for one of the simplest of data transmission systems. This system, however, is limited in capability to the less complicated signals. Simple circuits, similar to those shown in figure 2-3, are used to transmit an order or to indicate a condition.

In figure 2-3A, the switch is the transmitter, and the light is the receiver. When the ON/OFF switch is closed, the POWER ON light indicates that power is available to certain fire control equipment.

In figure 2-3B, the switch is the transmitter, and the relay is the receiver. When the START/STOP switch is closed, the RELAY energizes and orders the MOTOR to start.

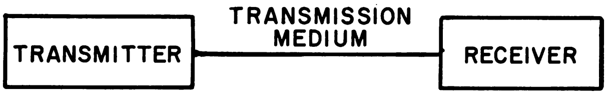

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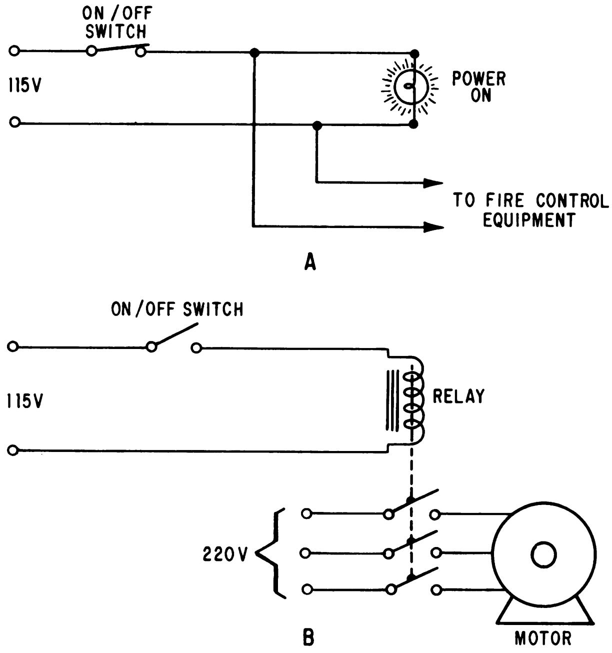
Figure 2-2.—Basic data transmission system.



166.175
Figure 2-3.—Simplified transmission circuits.

Even though switches and relays are simple, they are frequently used to indicate the status of fire control equipment (working or malfunctioning). They are also used to transmit orders to the personnel and equipment at remote units, if only "yes-no" information is required.

QUANTITIES AND NUMERICAL VALUES

Many fire control quantities, however, have quantitiative or numerical values that must be transmitted in order to describe them accurately. A quantity can be represented by an electrical value or by the mechanical position of a mechanism. In this chapter we will cover the devices used to convert a quantity into a convenient form for transmission.

But before we cover the devices, we will briefly discuss the concept of converting a quantity into a different but related form. The related form is referred to as an analog or scaled value of the quantity.

Most fire control quantities have numerical values. Numerals are symbols used to show the value or amount of a quantity or the position along a scale in a series of units. Hence, a target range of 100 yards indicates that the target is so many units, (100) (yards) away.

The unit of measure, yards, is not a convenient unit to use directly as a signal in a transmission system. A yard is a linear distance and would require a linear movement of that length to be used as a signal directly. If, however, we changed the unit to volts we could represent the target's range in an electrical circuit. We could possibly describe the range as 100 volts. This is not improper as long as the units (yard/volt) represent an equal distance and a change in range results in an equal or proportional change in the number of units. Obviously the ratio of a volt per yard is large and may not be suitable for many purposes. We can change this ratio. We shift scale in many types of measure; miles to yards and degrees to minutes of arc are examples. Thus, we could make one volt equal to 10 or to 100 yards. As long as the ratio between the units of measure is constant throughout their operational range, we are not incorrect.

A quantity can be defined in many types of measures. Hence, we can transmit quantities such as range, elevation, or train as voltages in an electrical circuit, as mechanical motions in a mechanical system, or as pressures in a hydraulic system. This is a basic concept in data transmission systems and in analog computers. We will discuss this concept further when we cover analog computers.

SYNCHROS

Synchro devices transmit fire control information electrically between distant stations. All fire control systems make extensive use of synchros; therefore, knowledge of them is important to you wherever you are stationed. It is assumed that you have a basic understanding of synchro principles. If you do not, it is advisable that you get the necessary background before continuing with this chapter. One source is the module covering synchros in the *Navy Electricity and Electronics Training Series (NEETS),* which is suggested as a prerequisite to this course.

Synchro Review

Before we cover the types and applications of synchros, we will briefly summarize their common features and characteristics. Synchros are basically transformers. Various types have been developed to serve several different purposes. They are usually position-sensing devices which have the following things in common.

1. They operate on a transformer principle.

2. They have a "Y" connected stator; that is, windings 120° apart, each with a common connection. (Think of these three windings as corresponding to one winding of a transformer.)

3. They have a rotor winding. (This is a rotating winding which corresponds to the other winding of a transformer.)

Synchros sense position in one of three ways:

1. The position of the rotor in relation to a reference point (mechanical information).

2. The voltage across the stator winding in relation to a predetermined reference voltage (electrical information).

3. The voltage across the rotor winding in relation to a predetermined reference voltage (electrical information).

As you know, synchro transmitters and receivers are energized with alternating voltage across their rotor windings (leads R1-R2). The turns ratio between rotor and stator is such that a MAXIMUM of 52 volts for 115-volt units or 6.8 volts for 26-volt units is produced across any one stator winding.

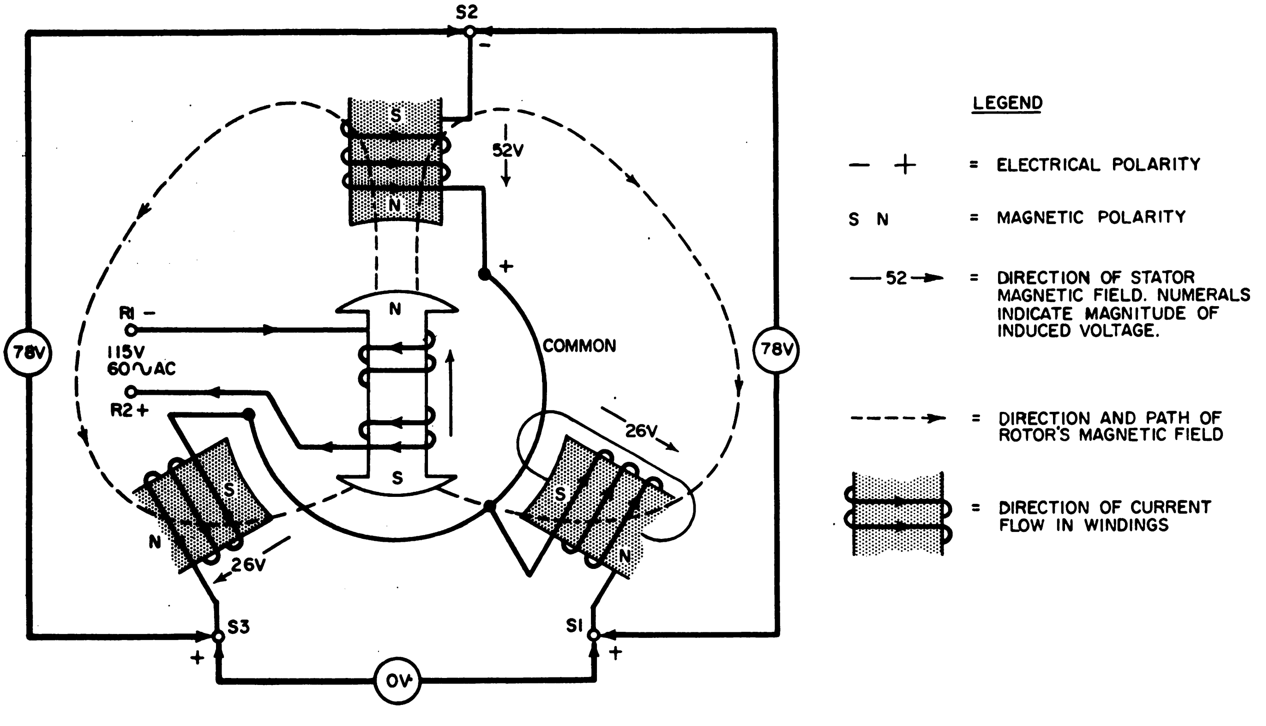
Figure 2-4 shows a synchro, either a transmitter or receiver, with 115-volts a.c. applied to its rotor. The synchro is shown with a rotor angle of zero degrees. Rotor angle is measured from the longitudinal axis of the rotor to the axis through the center of the S2 winding. The axis of the S2 winding is the standard reference point, called the ELECTRICAL ZERO point. All rotor angles are measured from this reference. The voltages on the stator windings at this position of the rotor are the reference values.

Classification of Synchros

We can classify the more common synchros by their function, size, supply voltage, and frequency. As you know, synchros are part of a system. The function of the system determines the types of synchros in it. If the synchro system provides a mechanical output (torque), which does the actual positioning of a load, it is a torque system. If it provides an electrical output which is used to control the power that does the mechanical work, it is a control system. Hence, synchros can be classified by the function they perform in the system. Table 2-1 lists the military abbreviation, inputs, and outputs of the more common functional classifications of synchros.

Identification of Synchros

Synchros that you will most likely encounter in ordnance equipment can be grouped into two broad categories: military standard synchros and prestandard Navy synchros. Military standard synchros conform to specifications which are uniform throughout the armed services. New equipments use synchros of this type. Prestandard synchros were made to meet Navy, rather than service-wide, specifications. Each category has a designation code for identification.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S
R1 -
115V
60∿AC
R2 +
COMMON
78V
78V
26V
26V
S
N
S
N
S3
S1
+
+
0V
LEGEND
— + = ELECTRICAL POLARITY
S N = MAGNETIC POLARITY
—52→ = DIRECTION OF STATOR MAGNETIC FIELD. NUMERALS INDICATE MAGNITUDE OF INDUCED VOLTAGE.
- - - -→ = DIRECTION AND PATH OF ROTOR'S MAGNETIC FIELD
= DIRECTION OF CURRENT FLOW IN WINDINGS

12.166

Figure 2-4.—Synchro voltages, rotor at zero degrees.

Table 2-1.—Synchro functional classifications

Functional Classification	Military Abbre-viations	Input	Output
Torque Transmitter	TX	Rotor positioned mechanically or manually by information to be transmitted	Electrical output from stator identifying rotor position supplied to torque receiver, torque differential transmitter, or torque differential receiver
Control Transmitter	CX	Same as TX	Electrical output same as TX but supplied only to control transformer or control differential transmitter
Torque Differential Transmitter	TDX	TX output applied to stator; rotor positioned according to amount data from TX must be modified	Electric output from rotor (representing angle equal to algebraic sum or difference of rotor position angle and angular data from TX) supplied to torque receivers, another TDX, or a torque differential receiver
Control Differential Transmitter	CDX	Same as TDX but data usually supplied by CX	Same as TDX but supplied only to control transformer or another CDX
Torque Receiver	TR	Electrical angular position data from TX or TDX supplied to stator	Rotor assumes position determined by electrical input supplied
Torque Differential Receiver	TDR	Electrical data supplied from two TDX's, two TX's or one TX and one TDX (one connected to rotor, one to stator)	Rotor assumes position equal to algebraic sum or difference of two angular inputs
Control Transformer	CT	Electrical data from CX or CDX applied to stator; rotor positioned mechanically or manually	Electrical output from rotor (proportional to sine of the difference between rotor angular position and electrical input angle)

12.3.28

MILITARY STANDARD DESIGNATION CODE.—This designation code identifies standard synchros by their physical size, functional purpose, and supply voltage characteristics. We will use two standard synchro designations, 18TR6 and 16CTB4a, as examples to explain the code. The first two digits indicate the diameter of the synchro in tenths of an inch, or to the next higher tenth. Thus an actual dimension of 1.75 inches becomes 18. The first letter indicates the general function of the synchro and of the synchro system: C for control; T for torque.

The next letter indicates the specific function of the synchro, as follows:

LETTER	DEFINITION
D	Differential
R	Receiver
T	Transfomer
X	Transmitter

The letter B following the preceding letters indicates that the synchro has a rotatable stator.

The number after the letters stands for the operating frequency:

6 for 60-hertz

4 for 400-hertz

The lower case letter is a modification designation. Successive modifications are in alphabetical order.

Thus, the 18TR6 is a torque receiver with a 60-hertz supply voltage and a diameter of between 1.71 and 1.80 inches. The 16CTB4a is a control transformer for use in a 400-hertz system. It has a rotatable stator, and a diameter between 1.51 and 1.60 inches. The lower case "a" indicates that the synchro has been modified once.

Type designations for all standard synchros are assigned by this code. Synchros for use in circuits supplied by 26 volts are classified in the same way, except that the symbol 26V is prefixed to the designator (26V16CX4 for example). Otherwise, a 115-volt source is assumed for the synchro system. Note that in table 2-1 only the functional designator is given. This is often the practice in OPs and in schematic diagrams. The complete identification is normally given in the physical description section of the OP.

NAVY PRESTANDARD DESIGNATION CODE.—This code identifies prestandard synchros as to their size and function by a number and letter combination. An example of a synchro identified by this code is a 5DG synchro. Unlike the standard code, the number does not directly indicate the diameter of the synchro. The number indicates relative size of the synchro. The size increases with the number. The letters indicate the function, mounting, or special characteristics as follows:

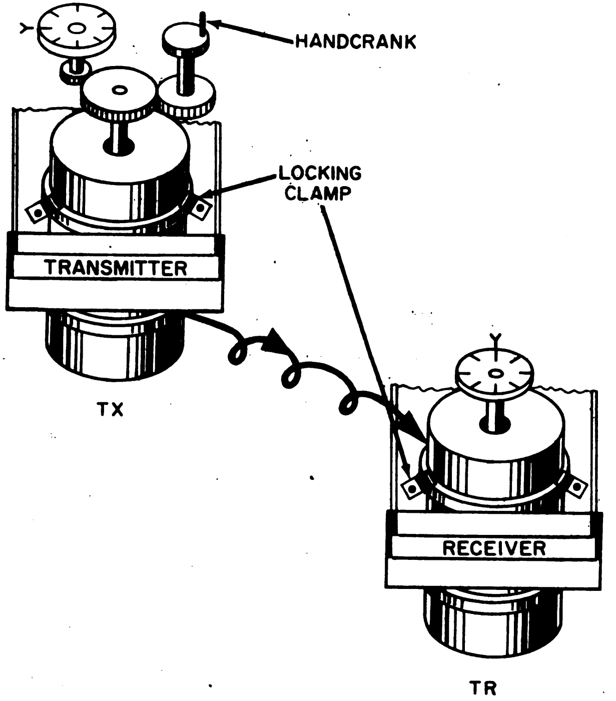
LETTER	DEFINITION
G	Transmitter
F	Flange Mounted Receiver, (this letter normally omitted if letters other than H or S occur in type designation.)
D	Differential Receiver
DG	Differential Transmitter
CT	Control Transformer
H	High Speed Unit
B	Bearing Mounted Unit
N	Nozzle Mounted Unit
S	Special Unit

In some texts synchro transmitters, TX, are called generators; and receivers, TR, are called motors. This is a carryover from the prestandard synchros.

Synchro Alignment

The primary function of a synchro system is to transmit information between remote units. The information is represented in the synchro transmission circuits as electrical potentials and currents which vary with the angular positions of the transmitter's and the receiver's rotors, as measured with respect to their stators. We can say, then, that the information as represented by electrical values in the circuits is in fact a measure of the angular displacement of the rotor from a reference point established by the stator. Hence, as previously mentioned, a synchro is basically a position-sensing device. To receive the transmitted information correctly there must be a reference point common to both synchros, and a common unit of measure.

To clarify this we will use a simple torque system (fig. 2-5). The TX rotor is coupled to a gear train and is mechanically restrained. The TR rotor is free to turn. Both the TX and the TR stators are stationary in their mountings. As you know, the axis of the S2 coil is the mechanical and electrical zero reference position of a synchro. Hence, we have a common point within the synchros from which the angular displacement of the rotors can be measured. But if the synchro system is to transmit a quantity properly, it must be interaligned with the instruments. In the system in the figure, this means that when we place the TX's dial on zero, which represents the value of the quantity in the transmitting instrument, the synchro must be at its zero position. Plainly the same is true for the TR and the receiving instrument; when the synchro is on zero, the dial should read zero. If the dials are identical, you can see that the synchros are aligned to identical reference points. This is true although the receiver's reference is at some distance from the transmitter's. When these relationships have been established, the quantity on the TX dial can be transmitted correctly between the instruments by the synchro system.



12.156
Figure 2-5.—Elementary synchro system.

Whatever the synchro system, either torque or control, the mechanical and electrical reference points must be aligned.

MECHANICAL ALIGNMENT.—Remember that the whole idea of a data transmission system is to get data from where it is to where it is needed. Therefore, the source of the data quantity (we will call it the transmitting instrument) and the receiver of the quantity (the receiving instrument) must be considered as parts of the system. Mechanical alignment is concerned with aligning the transmitting synchro to the transmitting instrument; aligning the receiving synchro to the receiving instrument; and aligning each synchro transmitter and receiver to its own common reference point.

As you have previously learned, the electrical axis of the S2 winding of a synchro is a reference from which the movement of its rotor is measured. (See fig. 2-4.) Thus, a synchro has a built-in reference—the position of the S2 winding, which is the connecting link between the mechanical alignment of the synchro with its instrument and the electrical alignment of the synchro system.

Every transmitting or receiving instrument has an assigned reference value or position for alignment purposes. This reference could be any value (or position) but is normally the zero position of the quantity in the instrument.

We now have two references, one for synchros and the other for transmitting and receiving instruments. To visualize how they are used, let's go back to the TX part of figure 2-5. (Note that the TR could also be used. The principles being applied are the same.)

You may consider that the dial and handcrank geared to the TX are parts of the transmitting instrument. Unlock the TX from the instrument's gears, and turn the handcrank until the dial reads the assigned reference value. Turn the TX rotor until it aligns with the S2 axis. When this is done and the two units are mechanically locked again, we can say that the reference positions of the TX and the transmitting instrument are coincident—if the TX rotor is at its electrical zero. Why coincident? Any quantity that can be made to vary linearly with the angular motion of a synchro rotor can be transmitted by a synchro system. (It doesn't matter that a quantity is basically linear, such as range and speed; only that a change in the quantity will change the synchro rotor position a proportional amount.) Thus, if the input from the transmitting instrument is at its reference, and the synchro rotor is at its reference then the positions are coincident.

If the synchro rotor is not at the electrical-zero position, however, the synchro must be adjusted further. The alignment is not over yet.

ELECTRICAL ZERO.—Each type of synchro has a combination of rotor position and stator voltages which is called its electrical zero. The electrical-zero condition is the reference point for the alignment of the synchro. We have defined the electrical zero and the mechanical zero as the condition in which the axis of the rotor is lined up with the axis of the S2 winding. Look back at figure 2-4. You can see that two such positions, 180° apart, are possible. The rotor is shown at the electrical-zero position, but if it were turned 180° we could still say it is lined up with the S2 winding. Let's see the electrical difference between these two rotor positions, and expand our definition of electrical zero.

In both the 0° position and the 180° position, the terminal voltage between S1 and S3 is zero. However, with an oscilloscope it can be seen that in the 0° position—the voltage from S2 to S3 or from S2 to S1 is IN PHASE with the voltage from R1 to R2, while in the 180° rotor position the voltage from S2 to S3 (or S1) is 180° out of phase with the rotor voltage.

The electrical-zero position is therefore completely defined as the position of the rotor in which the voltage between S1 and S3 is zero, and the voltage from S2 to S3 (or S1) is in phase with the voltage from R1 to R2.

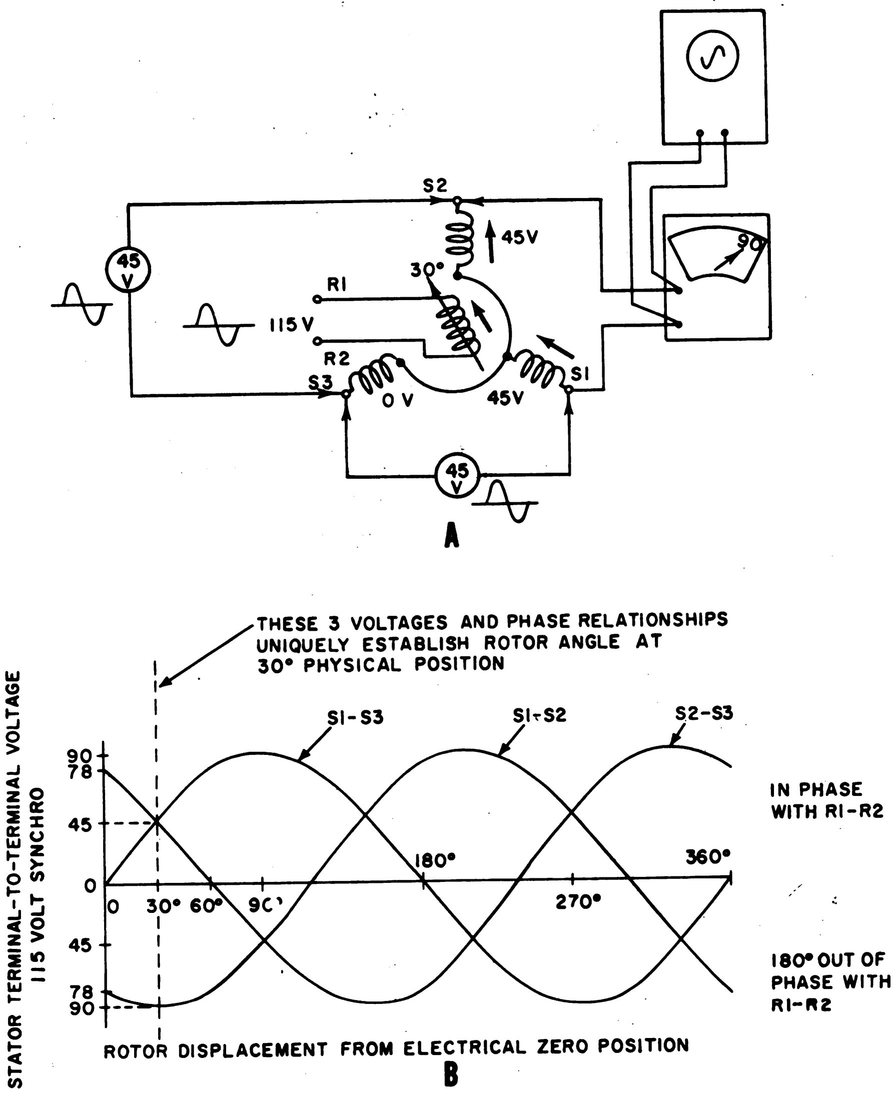
ZEROING PROCEDURE.—The alignment of a synchro system logically starts at the origin of the quantity being transmitted. For example, assume that you wish to align the synchro system that transmits director train. Naturally you would start at the director where this quantity originates. The first step in the alignment would be to set the director exactly on zero degrees in train. Next you would set the director's train transmitters on their electrical-zero positions. With the transmitters on zero, you can now set each receiver to its electrical zero. Since director train is a basic quantity, there will be many receivers in the system. But each receiver can be adjusted as an individual unit since the electrical-zero position is common to the whole system.

The specific procedure used to adjust a synchro to its electrical-zero position depends upon the tools you have and how the synchro is connected in the system. Each synchro is adjusted as an individual unit, but its interconnection with other units in the system must be considered. The *Military Standardization Handbook: Synchros, Description and Operation,* MIL-HDBK-225(AS), covers methods for adjusting all types of synchros under various conditions. The above handbook and background courses, such as *NEETS,* may be of benefit to you in refreshing your memory of electrical zeroing.

Synchro System Accuracy

A perfect synchro has never been made. Because a fire control system must be accurate, it is important that the system's synchros be made to operate within acceptable limits of accuracy. Certain design techniques and circuitry increase the accuracy of synchro system outputs. Your knowledge of these techniques and circuitry will help to prepare you for the many times you will be required to check the fire control system's accuracy and take corrective action if it is not acceptable.

SYNCHRO ERRORS.—Synchros will always cause some errors because of manufacturing inaccuracies and necessary assembly tolerances. You will remember that for each physical position of a synchro rotor there is a corresponding set of electrical conditions. For example, if you were to put the rotor of a theoretically perfect synchro transmitter at 30°, as shown in figure 2-6, the voltages you would


S2
45V
45 V
30°
R1
115V
R2
S3
0 V
45V
S1
90
45 V
A
THESE 3 VOLTAGES AND PHASE RELATIONSHIPS UNIQUELY ESTABLISH ROTOR ANGLE AT 30° PHYSICAL POSITION
S1-S3
S1-S2
S2-S3
STATOR TERMINAL-TO-TERMINAL VOLTAGE 115 VOLT SYNCHRO
90
78
45
0
45
78
90
0
30°
60°
90°
180°
270°
360°
IN PHASE WITH R1-R2
180° OUT OF PHASE WITH R1-R2
ROTOR DISPLACEMENT FROM ELECTRICAL ZERO POSITION
B

83.71

Figure 2-6.—Synchro electrical error.

read across the stator terminals would be as follows:

S1 to S2-90 volts and 180° out of phase with R1-R2.
S1-S3-45 volts and in phase with R1-R2.
S2-S3-45 volts and in phase with R1-R2.

These stator voltages and phase relationships are unique for 30° rotor position. (See fig. 2-6B.) You will not get these quantities at any other position of the rotor. But, as we said before, synchros are not perfect. Any difference between the actual physical position of the rotor and the electrical position is known as electrical error. (Sometimes the electrical error is called static accuracy.) It is possible, for example, to get the voltage readings and phase relationships listed above when the rotor of a real synchro is at, say 30° and 18 minutes. Therefore, the synchro has an electrical error of 18 minutes. If this is fed to a servo, then the servo output will reflect the electrical error. Let's see how electrical errors show up in a synchro system.

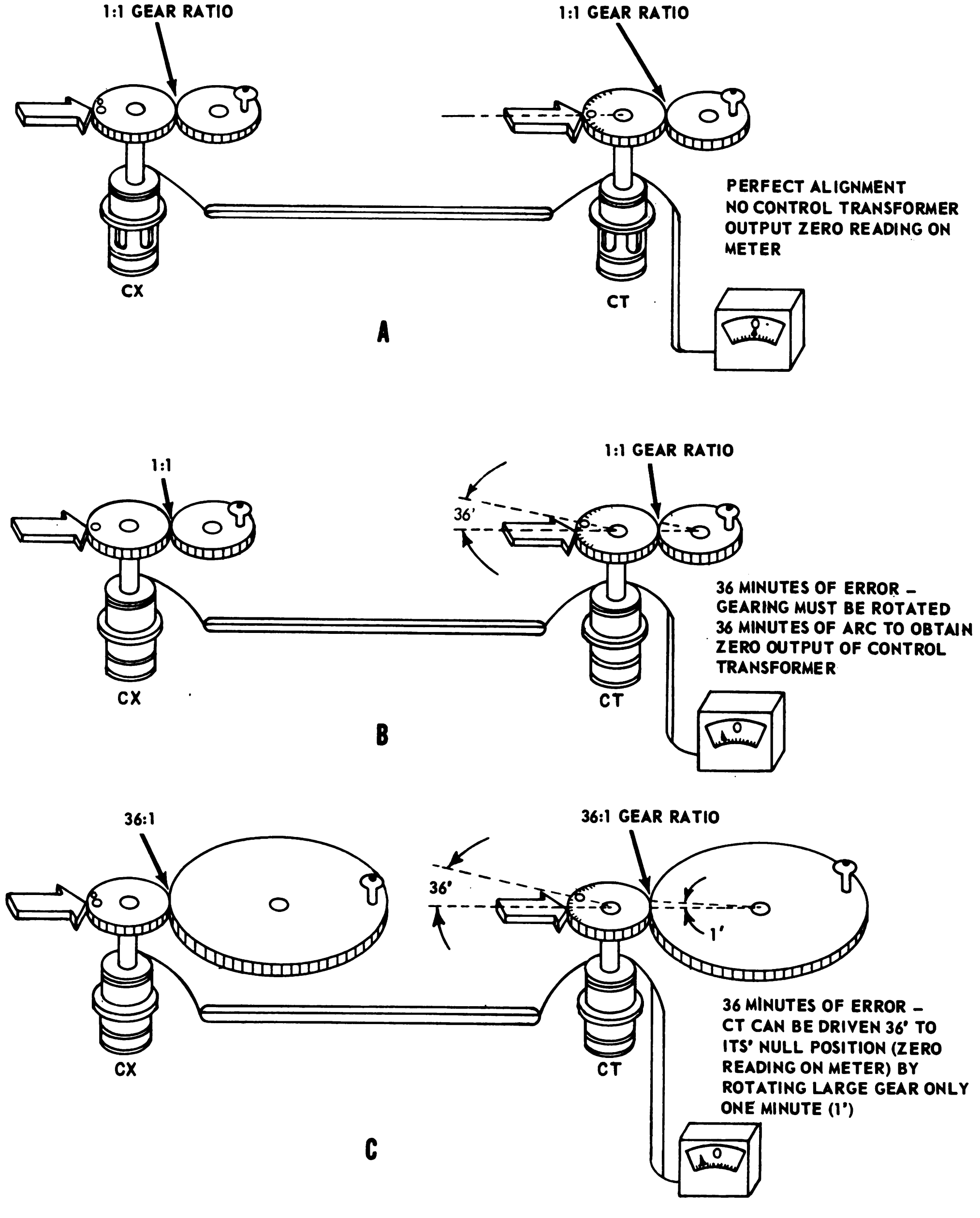
The pictorial diagram in figure 2-7A shows a control transmitter (CX) and control transformer (CT). We will assume that it is a perfect system. It has no electrical error. Notice particularly that all gear ratios are 1:1. That is, if we turn the transmitter handcrank one revolution, the transmitter rotor will turn one revolution (360°). Similarly, if you turn the CT's handcrank one revolution, the control transformer rotor will turn one revolution. Furthermore, assume that the dials on both rotor gear faces are so accurate that we can read angular position of the respective rotor in minutes of arc as well as degrees of rotor angular position. The voltmeter is hooked across the R1-R2 leads of the CT. Remember that this voltage at any instant is a reflection of the data transmitted from the CX.

Since we have a theoretically perfect system, if we put the rotor of the CX on zero, and turn the crank at the CT end until the voltmeter reads zero, then the dial on the CT will be at zero—showing perfect alignment with the CX. If we turn the rotor of the transmitter to 5°, as read on the CX rotor dial, and then turn the control transformer handcrank until the voltmeter reads zero volts, a glance at the CT dial will show that it reads exactly 5°. You can repeat this experiment for every position on the dial, and the result will be that when the transmitter rotor is at a selected position, the CT rotor will be at the same position when the voltmeter reads zero. In other words, we have perfect transmission of data.

But now look at what happens when we use actual synchro units in the system.

The pictorial diagram in figure 2-7B shows the same setup as we had before. But instead of perfect synchros, we have replaced them with more realistic ones that have an electrical error of 18 minutes apiece. If we put the dial of the transmitter at zero, we will transmit what we think is an electrical signal proportional to zero degrees. But to get a null (minimum or zero reading of the voltmeter), the CT rotor must be turned through an angle of 36 minutes. At null it is obvious that the two rotors are not in the same angular position. The transmitter rotor is at its zero position and the control transformer rotor is 36 minutes away from zero. If the CX and CT of figure 2-7B were controlling the position of a radar antenna, the antenna would not end up in the ordered position. It would be close, maybe, but not precise. A system such as this that gives approximate results is called a COARSE system, because it transmits angular position information that contains relatively large error. Therefore, an additional synchro system, called a FINE system, is used along with the coarse system.

FINE SYNCHRO SYSTEM.—We can make a fine system out of the coarse system we have just talked about simply by changing gear ratios. (See fig. 2-7C.) Instead of a 1:1 gear ratio between the synchro rotors and their handcranks, we have installed gears with a ratio of 36:1. If we turn either handcrank one revolution, its associated rotor will turn 36 times. Also, it follows that if we turn either crank through one minute of arc then the rotor geared to the crank will turn through 36 minutes. Now, mentally place both dials at zero. Assume that we have a 36-minute electrical error in the


1:1 GEAR RATIO
1:1 GEAR RATIO
PERFECT ALIGNMENT NO CONTROL TRANSFORMER OUTPUT ZERO READING ON METER
CX
CT
A
1:1
1:1 GEAR RATIO
36'
36 MINUTES OF ERROR - GEARING MUST BE ROTATED 36 MINUTES OF ARC TO OBTAIN ZERO OUTPUT OF CONTROL TRANSFORMER
CX
CT
B
36:1
36:1 GEAR RATIO
36'
1'
36 MINUTES OF ERROR - CT CAN BE DRIVEN 36' TO ITS' NULL POSITION (ZERO READING ON METER) BY ROTATING LARGE GEAR ONLY ONE MINUTE (1')
CX
CT
C

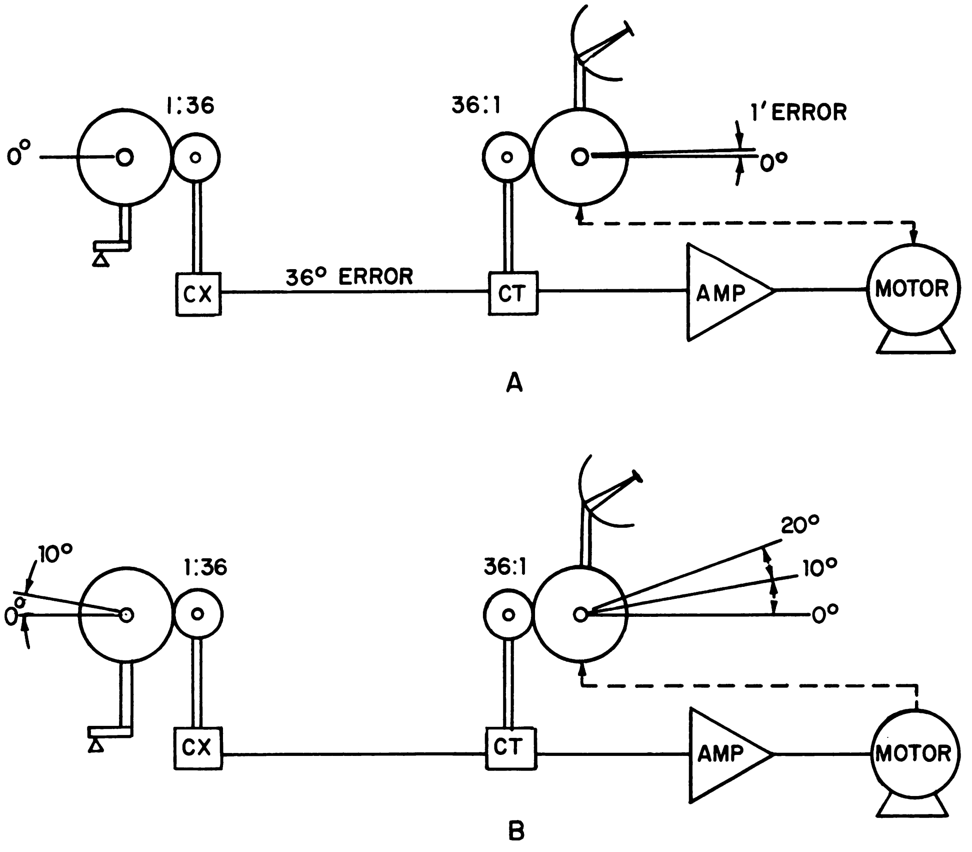
83.72

Figure 2-7.—Electrical error in a synchro system.

synchro system. With the increased gear ratio, we have to move the control transformer handcrank only one minute to null the voltmeter. So, by increasing the gear ratio we have divided the effect of the error by 36. Remember, in an identical situation using the coarse (1:1 ratio) system of figure 2-7B, we had to move the CT rotor 36 minutes to get system null.

In the preceding discussion about synchro system electrical error, we manually turned the CT handcrank which moved the CT rotor until we saw a zero reading on the meter dial. Now let's replace the human operator with a motor and show how increased gear ratios improve the accuracy of the synchro system. The diagram in figure 2-8A shows an antenna power drive motor controlled by a fine synchro system. Assume there is a 36-minute accumulative error in the synchro system, and that the input shaft (CX rotor shaft) and the antenna are both at their ZERO positions. At this point, because of the 36-minute error, the CT is not nulled. The 36-minute error causes a voltage to be applied to the amplifier, which, in turn, causes the motor to drive the antenna through a one-minute angle. (Remember that the 36-minute error has been divided by 36 because of the gear ratio at the CX.) As the antenna moves through the one-minute angle, the CT rotor, because of the gear ratio, is driven 36 minutes. This nulls it, reducing the amplifier voltage, and stopping the motor. The important point is that even though the error in the transmission system remains at 36 minutes, the antenna is only one minute from being where it should be. A coarse system would have allowed the full 36-minute error between input and antenna.

DISADVANTAGE OF FINE SYNCHRO TRANSMISSION.—The main disadvantage of the 36:1 transmission is that the output shaft to the antenna (fig. 2-8B) can be in correspondence at 36 different points for any one revolution of the input shaft to the CX. To illustrate this, assume that the rotors of the energized CX and CT are at 0° when we remove the electrical



166.176

Figure 2-8.—Fine synchro system.

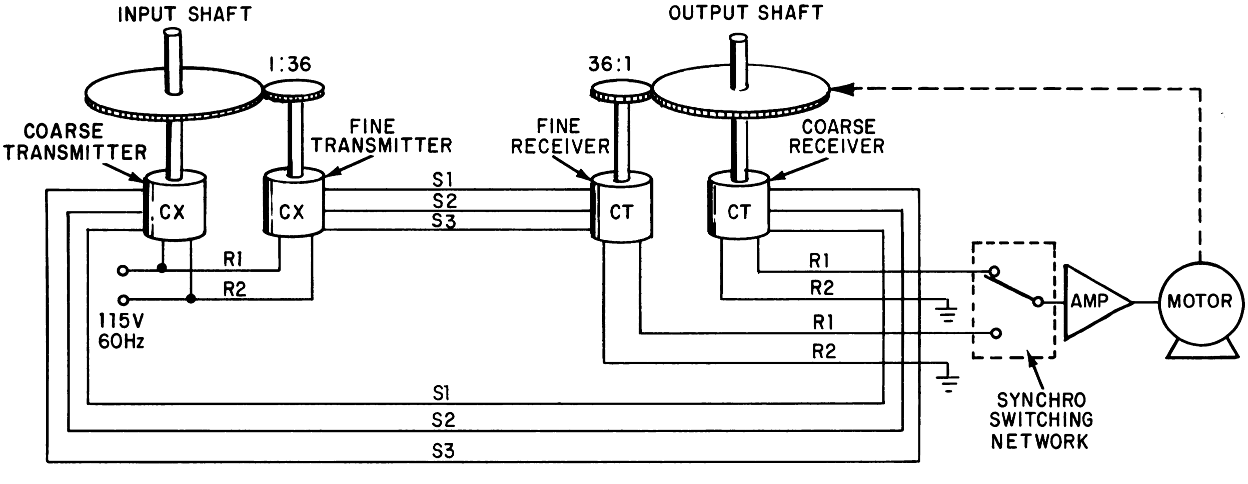
power. Now, if we turn the input handcrank to 10°, and then turn the power back on, we find that the antenna remains at 0°, even though the CX is transmitting 10°. This is because the CX rotor made one complete revolution (which is right back at the zero position) in responding to the 10° input of the handcrank. You can see that, if the system is put in service at this point, the antenna will be 10° away from its ordered position and will remain off by that amount even when the input is changed.

Removing electrical power and then reenergizing the synchros was used in the above paragraph to show that any break in service between the synchros could result in erroneous readings. The possibility of false correspondence between the CT and the CX exists at each 10° point (36 separate points) for each revolution of the input shaft. This disadvantage is the reason why fine systems by themselves are seldom seen.

COMBINING THE FINE AND COARSE SYSTEMS.—Although the fine system provides high accuracy, it is seldom used by itself. As you have seen, it does not provide true synchronization between the input and output at all times. We certainly would not want the antenna pointed at 80° when the synchro transmitter rotor shaft was at, say 10°. A common solution is to combine a fine system with a coarse system. A simplified schematic is shown in figure 2-9. The fine synchro system provides a very sensitive control at times when the error between the order signal and the output is small. However, because the fine system can synchronize at any one of 36 positions, the coarse system is needed to bring the antenna close enough to the true synchronous position so that it is within the range of the fine synchro.

The following paragraph will summarize how this is accomplished and should serve to refresh your memory of this subject from *NEETS* or other background sources.

Only one of the two receiver synchros in figure 2-9 is in control at any given instant. A mechanical or electrical sensing device, called a synchro switching network, senses the voltages from the receiver CT's and determines which system drives the motor. When there is a large transmission error, there is a large error voltage from the coarse receiver CT. As the synchro system responds to null the transmission error, the error voltage of the coarse CT reduces in amplitude. When the coarse CT voltage reaches a predetermined level, the synchro switching network switches over to the error voltage of the



166.177

Figure 2-9.—1-and-36 speed system.

fine CT. Now the fine CT will drive the motor and deliver the final, accurate information needed to null the transmission error and drive the output shaft as ordered.

Fine and coarse systems are known by other names such as dual-speed or 1-and-36 speed systems. No matter what they are called, they are what we have just discussed.

ZEROING DUAL-SPEED SYNCHRO SYSTEMS.—When zeroing a dual-speed synchro system, you can consider each synchro as an individual unit. Each synchro must be aligned mechanically and electrically to the fire control instrument as mentioned earlier. However, when the alignment is complete, you must be careful to ensure that the coarse and fine synchro systems are at the same electrical-zero position. Let's see why.

Assume that the coarse CX transmits a signal to which the coarse receiver responds and drives to its approximate position. At this point the switching network activates and the fine synchro takes control. In driving to its zero, the fine synchro pulls the coarse system enough out of correspondence to generate a large error signal. The switching network responds by returning control to the coarse system. Thus, the two systems, because of not having a common zero, tend to buck or oscillate between each other.

The above problem can be solved by ensuring that both systems have a common electrical zero. First, establish the zero position for the coarse synchro system. When this is complete, establish the zero position for the fine synchro system. Just remember that all the synchros in a transmission system must have a common electrical-zero position.

There are a few three-speed synchro systems. These systems are zeroed in the same manner as the dual-speed systems.

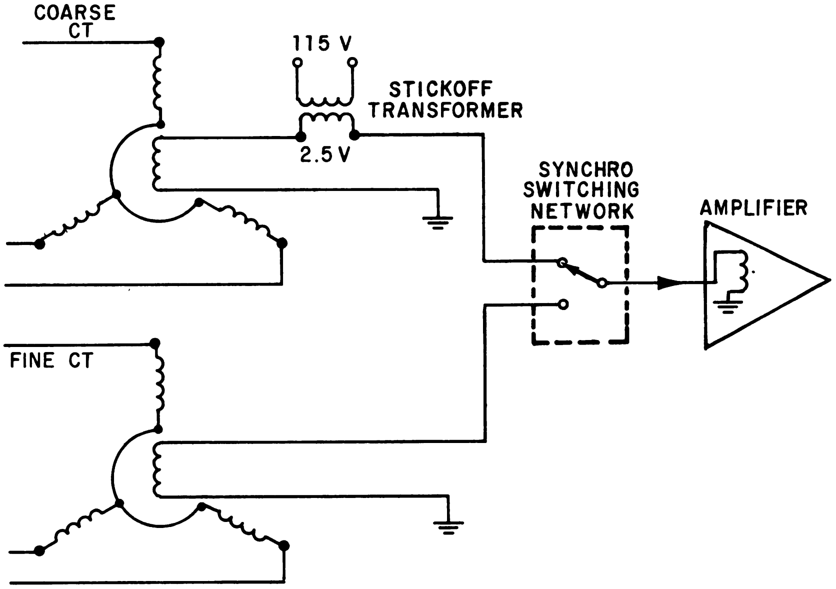
The fact that the receivers in a synchro system are zeroed together leads us into the next subject.

Stickoff Voltage

The motor in figure 2-9 will stop driving when the error signal reaches zero. A CT, however, has two positions, 180° apart, where its output is zero. Thus, a motor controlled by a CT can synchronize at either position. This is possible in a dual-speed synchro system with an even speed ratio. Since both receivers are zeroed together, both would be at the true correspondence and the false correspondence positions together. Hence, a motor could not distinguish between the two positions. In fire control systems where remote and often unattended servomotors are used, the possibility that a false synchronization could occur must be eliminated.

As mentioned previously, no CT is perfect. Each has an inherent dead space. But, the fine signal has little or no dead space. The slightest change in the signal or movement of the motor's reponse will bring the fine CT out of its dead space. Once out of its dead space, the fine CT will cause the motor to drive. You might think then that we do not have a false synchronization problem. But, suppose that when the system is energized, the transmitters and receivers are close to being 180° apart. The coarse signal would be too weak to assume control of the system, and the fine CT would have control. The motor would drive until the fine signal was zero and would remain there. The motor could not sense the difference between 180° and zero synchronization.

In order to make all positions distinguishable, a "stickoff" voltage is applied to the coarse signal. In figure 2-10 the secondary winding of the stickoff transformer is shown in series with the coarse CT output. Here is how it works. At the electrical-zero position, the 2.5-volt stickoff voltage is applied so that it is 180° out of phase with the induced rotor voltage. The coarse CT stator is now rezeroed so that the induced rotor voltage and the stickoff voltage cancel each other. The effective voltage is zero at the true electrical-zero position. When the rotor of the coarse CT rotates 180° to the false sync position, the voltage induced in the rotor is in phase with the stickoff voltage. The two voltages add at this point, producing 5 volts from the coarse CT. This 5-volt difference in rotor output between the two positions 180° away from each other makes the two positions



12.280

Figure 2-10.–Stickoff voltage in coarse signal circuit.

distinguishable. Because the coarse CT has a 5-volt error signal when it is 180° out of synchronization, the motor will continue to drive until the true, or zero, synchronization point is found.

Troubleshooting Synchro Systems

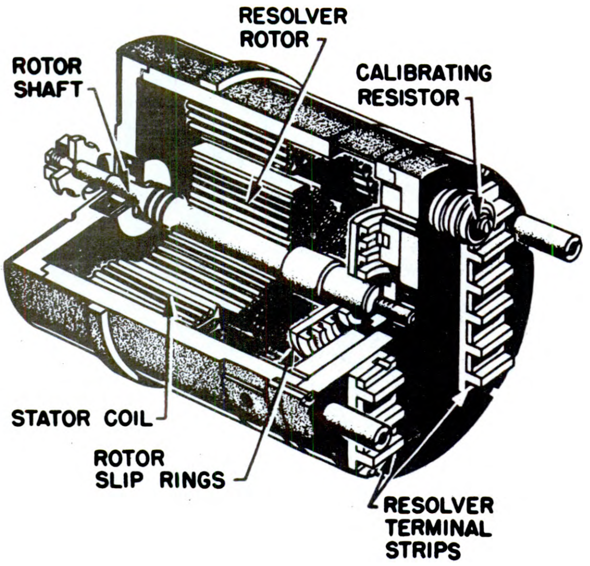
Troubleshooting synchros is basically simple. If they are damaged, you must replace them. If they are misaligned, you must realign them. It is your job to distinguish these differences and take the appropriate corrective action.

There are several publications available to you which assist in troubleshooting and repairing synchro systems. The *Military Standardization Handbook (Synchros) Description and Operation,* the appropriate *Navy Electricity and Electronics Training Series* module(s) (*NEETS*), and of course, the OPs of your fire control system are excellent sources of information.

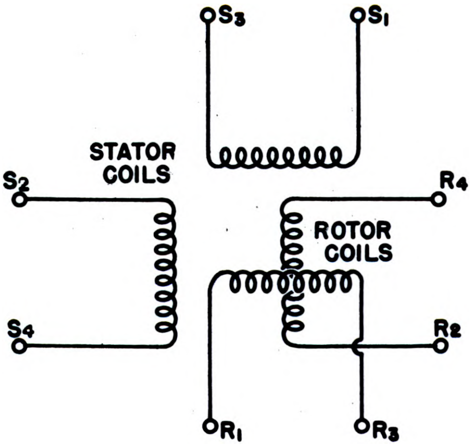
PROTECTIVE DEVICES.–Many synchro systems have one transmitter to transmit information to several receivers. These receivers are located at the various fire control stations throughout the ship. Because all the receivers of each system are in parallel, a fault such as an overload or short circuit in one instrument affects the operation of the entire system. When trouble occurs in such a system, it is difficult to determine which unit is faulty. The use of overload and blown-fuse indicators provides a means of locating the faulty instrument. Various types of blown-fuse indicators are used. These devices usually employ small neon-glow indicators in parallel with the fuse element. Overloads are indicated by a trouble light that is operated by a small transformer located in the switch panels on the fire control switchboard.

RESOLVERS

In appearance and construction, the resolver is similar to the synchro. (See fig. 2-11.) The use of the term resolver for this unit comes from the fact that it is used to resolve a vector quantity into its sine and cosine components. In other



12.106
Figure 2-11.—Cutaway of a resolver.



12.105
Figure 2-12.—Resolver schematic.

words, a resolver has the ability to input a vector quantity and output the two right-angle components of that vector. Conversely, the resolver may be fed the two components and produce the resultant vector as transmitted data.

A resolver is a variable transformer which requires an a.c. voltage input. It consists of a stator and rotor, and is capable of unlimited rotation. Besides the transmission of data, resolvers perform mathematical computations involving trigonometry (solving angle and vector problems). Their uses in computation will be discussed in a later chapter.

Figure 2-12 shows a schematic diagram of a resolver. It consists of a stator and rotor, each wound with two separate coils placed precisely at right angles to each other. Since the two stator windings are physically and electrically at right angles to each other, if an alternating voltage were applied to the windings, there would be no magnetic coupling between them. The stator windings are mounted on the resolver housing and are stationary with respect to it.

The rotor windings of the resolver are wound at right angles to each other. Hence, there is no magnetic coupling between the two windings. The rotor windings are mounted on the same rotor shaft and will turn with it. The rotor is capable of unlimited rotation. Thus, the rotor windings can be set at any angle with respect to the stator windings.

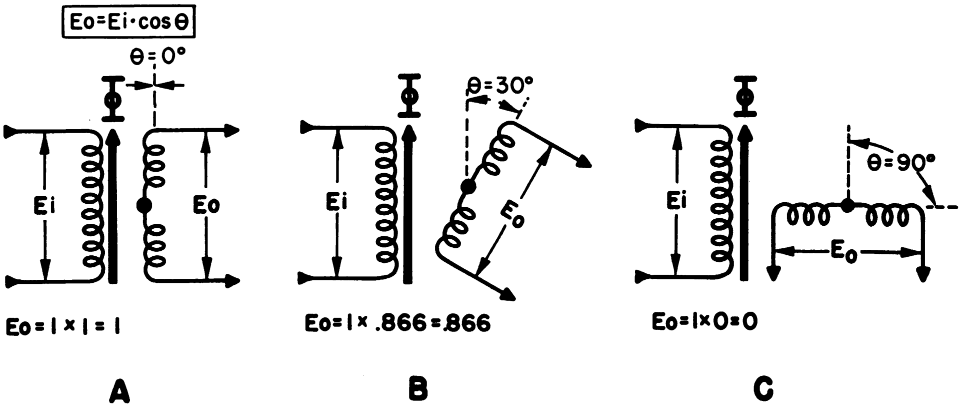
A resolver is strictly a signal producing device. The stator and rotor windings are wound from very fine wire and cannot pass enough current to develop torque. Therefore, any rotation of a resolver's rotor must be accomplished by some external force, a motor or a handcrank, for example.

The input-to-output signal ratio of a resolver is 1:1. The controlling a.c. input signal may be brought in on either the stator or the rotor, and the output is taken from the opposite winding. This depends on how the resolver is being used, as we will see in the pages that follow.

Resolver Operation

A resolver has both electrical and mechanical (rotation) inputs. The outputs are electrical, and are proportional, electrically, to the sine or cosine of the angle through which the rotor has been turned.

For a better explanation, let's take a look at figure 2-13. For simplicity, we will use only one



12.107

Figure 2-13.—Resolver principle, rotor and stator.

set of stator and rotor windings. But, keep in mind that a similar action takes place in the windings that are not shown.

The figure shows the rotor at three different positions with respect to the stator. The inputs are a constant a.c. voltage (Ei) to the stator and the mechanical rotation of the rotor. The output is an a.c. voltage (Eo) taken across the rotor winding.

In figure 2-13A, the rotor and stator windings have an angle of 0° between them. With the rotor in this position, all the flux established by the stator winding voltage cuts the rotor winding and the voltage induced in the rotor is maximum. For example, with a turns ratio between the stator and rotor of 1:1 and an input voltage of 1 volt, ignoring the small transformer losses, the output voltage will be 1 volt.

In figure 2-13B, the rotor is turned so that the two windings are displaced by 30°. Now only a part of the stator flux cuts the rotor winding, and the voltage induced in the rotor is 0.866 volts.

In figure 2-13C, the rotor is turned so that the two windings are displaced by 90°. At this angle there is no magnetic coupling between the windings, and the output voltage is zero.

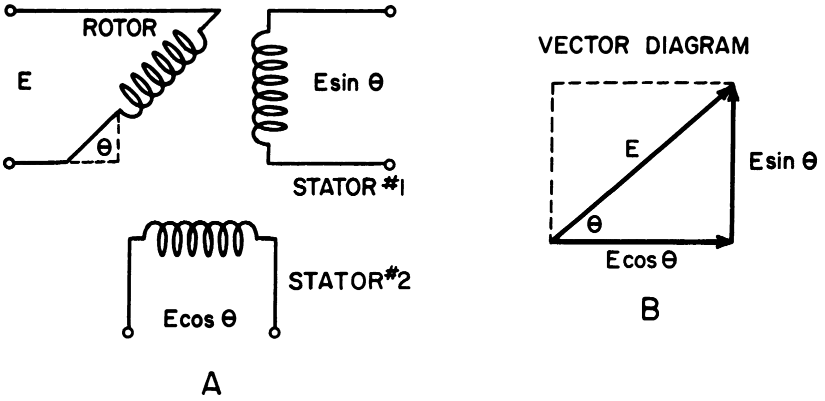
The output voltage corresponds numerically to the cosine function of the angular displacement between the rotor and stator. This rotor winding is therefore called the cosine winding. With the second rotor windings displaced 90° from the cosine winding, the voltage induced in this winding would correspond to the sine function of the angle of displacement between the rotor and the stator. This naturally would be called the sine winding.

Resolver Application

Now that you have seen what goes on inside a resolver, the next step is to see how it is used for the transmission of data.

In this application, our transmitting resolver shown in figure 2-14 is sending information in the form of a vector. This information could be bearing and range, course and speed, or any quantity that has both direction and magnitude.

Briefly, if you apply an a.c. input voltage, labeled E in figure 2-14A, to the rotor winding (in this example the rotor uses only one winding), the output voltages from the two stator windings will be sine and cosine functions respectively of the angular position (θ) of the rotor. In other words, as shown in figure 2-14 they will be equal to E sine (θ) and E cosine θ. Referring to the vector triangle in part B of

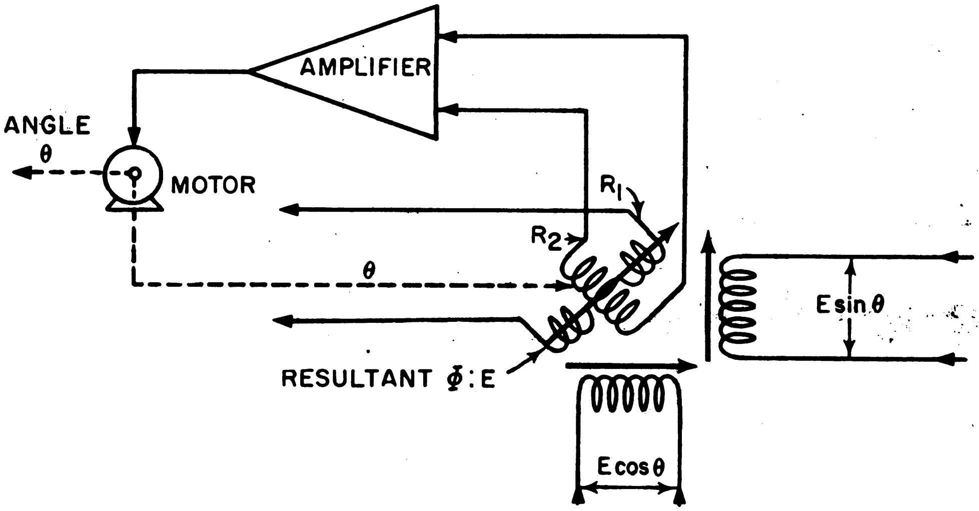


55.28

Figure 2-14.—The resolution of a voltage.

figure 2-14, where the vector E is drawn as the resultant or hypotenuse of the triangle, you can see that the resolver actually breaks down or resolves vector E into its two rectangular components. This process is called resolution of vectors.

The voltages representing the two sides of the right triangle are applied to the stator windings of a second resolver, (fig. 2-15). This resolver is located in a remote instrument and is what we would call a receiver in the transmission system. The two input voltages, E sin θ and E cos θ, produce a resultant flux field. Voltages are induced in the two rotor windings, R1 and R2, from the flux field. R2 is connected to a motor through an amplifier. The motor will drive the rotor until R2 is at right angles to the



12.283

Figure 2-15.—Receiver in a resolver transmission system.

flux field. At this position of the rotor, its angle is equal to θ and no voltage is induced into R2. The winding R1 is cut by the entire flux field, and the voltage induced is proportional to voltage E (which represents the hypotenuse of the triangle.)

The resolver is at its null position with the rotor at angle θ and its output voltage proportional to the triangle hypotenuse. If either of the stator input voltages change, the resultant flux field will change and a voltage will be induced into R2 which will feed a signal to the amplifier. The motor will drive until the signal is again nulled. At this point the induced voltage in R1 represents the new hypotenuse and the rotor is at the new angle θ.

It can be seen from this discussion that there is a definite relationship between the mechanical input and the electrical outputs of a resolver. Therefore, we can use them to develop signal voltages in data transmission systems. Resolvers have this feature in common with synchros, but resolvers are more accurate and, as we will learn later, much more versatile.

Resolver Compensators

Voltage regulation is very important because resolver voltages represent quantities in the fire control problem. If the voltage regulation is poor, the resolver will introduce errors into the problem. But resolvers are variable transformers, and changes in the angular position of the rotor will change the impedance or load as seen by the stator windings. Thus, the current in the resolver will vary and affect the magnitude and the phase of the resolver voltages.

The calibrating resistors shown in figure 2-11 are precision resistors that serve two purposes. First, they compensate for voltage inaccuracies in the winding and phase shifts introduced by load changes. Second, they are used to standardize the electrical characteristics of a resolver type.

To increase a resolver's accuracy, its input voltages are supplied through compensators. These are regulating circuits consisting of reactance (coils and capacitors) and resistance components in series with the resolver windings. Their purpose is to make the input voltages independent of the varying current in the circuit.

The resolver compensators that we have discussed so far are designed and internally installed by the manufacturer. Whenever you detect a malfunction in a resolver, you simply replace it.

Occasionally, you will find some compensator capacitors located on the outside of the resolver. These capacitors will be wired to the rotor and stator terminals on the resolver. Whenever this type of resolver is replaced, the capacitors must be transferred from the old to the new resolver in the exact fashion they were previously in.

Booster Amplifiers

To reduce the voltage regulation troubles in circuits where the output of one resolver is the input to another resolver, a booster amplifier is connected between the resolvers. The amplifier has a high input impedance and a low output impedance, and acts as an isolation circuit. It is essentially a power amplifier with approximately unity voltage gain and a zero phase shift. Thus, the amplifier can supply an appreciable amount of power to its output circuit while drawing only a negligible amount of power from its input circuit. Consequently, variations in the load are compensated for in the amplifier and the signal voltage to the receiver resolver has the correct magnitude and phase.

We will cover the circuits in a booster amplifier in a later chapter. Complex or simple however, there is one thing you will find in every booster amplifier—nearly 100 percent negative feedback. That is what makes them voltage regulators. Negative feedback is used because of its ability to stabilize a circuit and maintain the gain constant under varying loads and d.c. supply voltages.

Zeroing a Resolver

Before a resolver can transmit data, it must have a reference position from which the input values are measured. The reasons for this are the same as those previously studied under synchros. As with synchros, this position is known as the reference position.

There are many methods used to zero resolvers. Each manufacturer has a method. The method described below uses the basic principle underlying all of the different resolver zeroing methods.

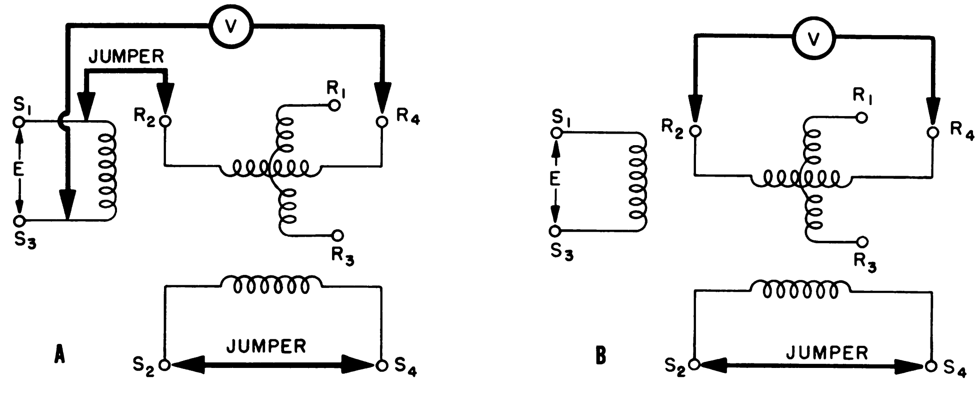
The zero position of a resolver is determined by the angular relationship between the rotor and stator windings. Each stator winding must be perpendicular to a corresponding rotor winding. When this relationship is established, there will be no magnetic coupling between corresponding windings.

COARSE ZEROING.—The absence of a magnetic coupling between corresponding rotor and stator windings is possible at two positions 180° apart. To ensure the correct position, so that the phase relationship between the rotor and stator is correct, the coarse-zero test is made first. Figure 2-16A shows the connections for the coarse-zero test. The voltage applied to the stator winding S1-S3 is a reference voltage specified for the resolver. The two windings are connected in parallel by the voltmeter and the jumper. The voltmeter will read the applied voltage, plus or minus any voltage induced in the rotor winding. The jumper across the winding S2-S4 is to eliminate any stray voltage that might originate from the winding.

To make the coarse-zero adjustment, loosen the flange mounting screws of the stator, looking at the rear (brush end), turn the stator counterclockwise. Stop turning when the voltmeter reads the input voltage, E. At this point you know the R2-R4 coil has no induced voltage because the voltmeter reads the input voltage alone. This means that the R2-R4 is approximately at right angles to S1-S3 and the rotor is at coarse zero.

With the voltmeter reading the E voltage, turn the stator a little more counterclockwise beyond coarse zero. The voltage at the voltmeter should INCREASE ABOVE E, because the voltage induced in the R2-R4 coils adds to E. Be sure the voltage at the voltmeter increases to prevent zeroing at 180° out of phase.

FINE ZEROING.—The next step is to set the resolver on fine zero. Figure 2-16B shows you how to reconnect the jumper and voltmeter. Turn the stator so that the voltage on the voltmeter decreases, and keep shifting the meter to the lower scales until the minimum voltage reading is obtained. The minimum voltage reading means that R2-R4 is exactly at right angles to S1-S3, and the rotor is at fine zero.



12.111

Figure 2-16.—A. Coarse zero; B. Fine zero.

Recheck this voltage after you secure the mounting screws.

Resolver Maintenance

The maintenance of resolvers consists mainly of testing and replacement. Internal repair of a resolver normally should not be attempted aboard ship. A resolver is a precision component, whose electrical characteristics are critical, and any deviation may result in excessive errors in the system. The procedures for testing resolvers are covered in your system or instrument OP. Here we will discuss the general principles involved.

The test run on a component is determined by the functions it performs in a system or circuit. Therefore, if we know the function and operation of a component, the test that checks it can be readily understood. This is elementary and of course will hold true for resolver tests. In fact, we could go back to the zeroing procedure and just about leave it at that, for resolver maintenance starts and ends with alignment tests.

If you understand how to zero a resolver, you will have no trouble understanding the operational tests of a resolver. The zero position is our reference point for these tests. The mechanical input to the resolver is positioned at a known angle, and a voltage reading is taken. The input voltage, which usually is a reference voltage set at a predetermined value, is checked first. Then the resolver's output voltages are read and the voltage values are compared with those listed in the OP. If you study them, you will find the output voltages are related to the input voltages by the sine and cosine functions of the angular input. For the test to be accurate, be sure the exact reference voltage is used. Moreover, if the wrong voltage is used, it is quite possible you will damage some of the components in the circuit. The OP will specify the type meter to use in the test, because there is a degree of inaccuracy in every meter.

Frequently the OP will list the resistance reading of the resolver windings. These are given for testing only; no repair aboard ship is intended. If it is necessary to replace a resolver, be sure the replacement is the same type. The resolver's compensating resistors are used to standardize a resolver type. Therefore do not attempt to adjust these unless the OP gives definite instructions on it. The same thing holds true for the resolver's compensating circuits.

STEP TRANSMISSION SYSTEM

A step transmission system is used to transmit coarse angular positions in steps. In this system, the transmitter, in effect a rotary switch, applies voltages to a special type of motor, the receiver, so that the motor shaft turns in step with the switch's shaft. This type of transmission system is used in applications where the precision of synchros and resolvers is not required. A good example is the automatic operation of remotely located switches of a fire control system. The advantages of step transmission are that the system is inexpensive, rugged, and relatively powerful.

A step transmission system consists of a transmitter and a motor as shown in figures 2-17 and 2-18. When you rotate the shaft of the step transmitter, a d.c. source voltage is switched from one pair of coils to another in the step

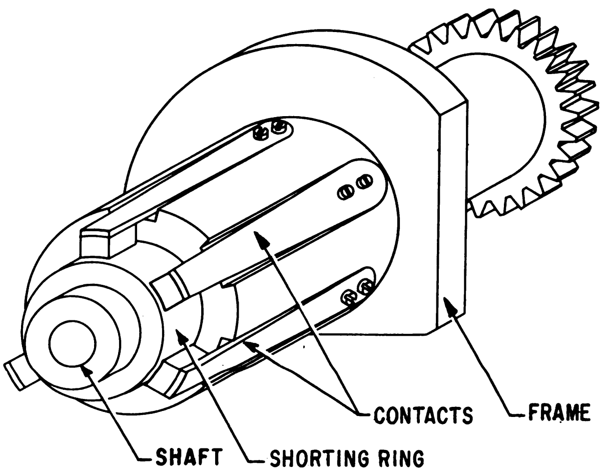


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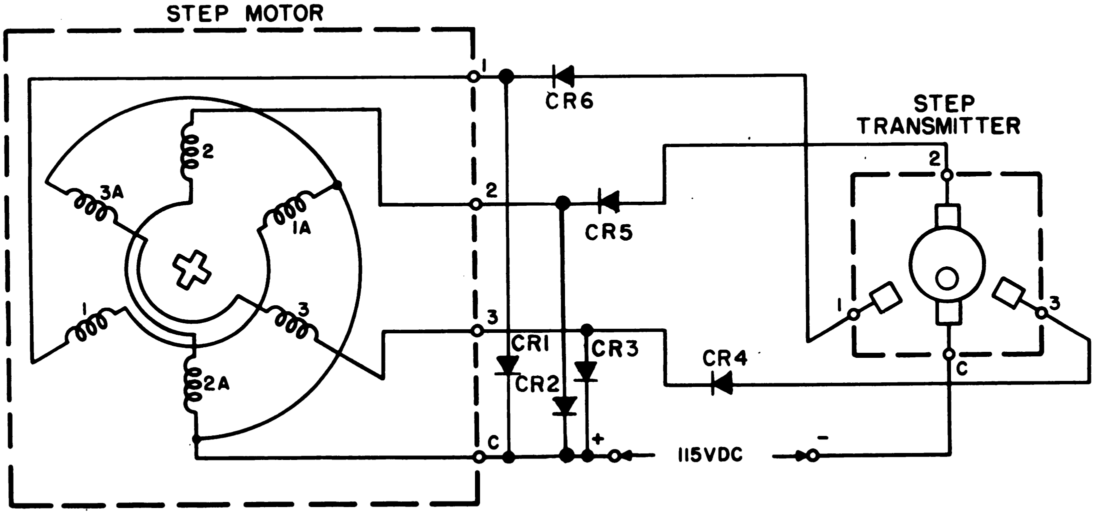
Figure 2-17.—Step transmitter.



166.8

Figure 2-18.—Step motor and step transmitter.

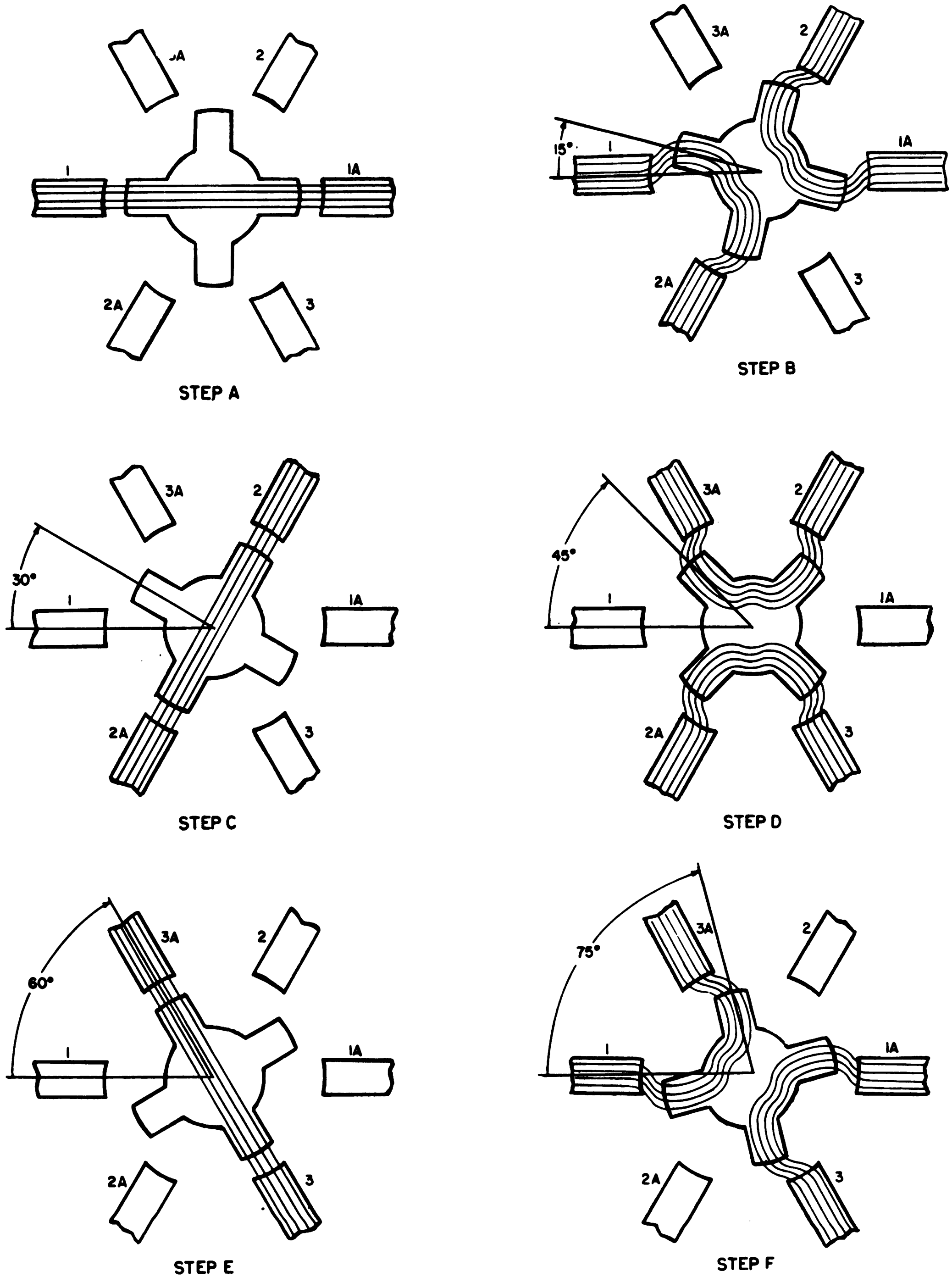
motor. The step motor, which is the receiver in the system, responds to this exitation voltage by rotating an amount that is proportional to the transmitter's rotation.

The step transmitter (fig. 2-17), has an electrically insulated frame, a shaft, an eccentrically mounted shorting ring, and four contacts. The shorting ring is surrounded by the four contacts, which are fastened to the ends of flat, conducting spring arms. Each spring is secured in a slot in the insulated frame. During a complete revolution of the step transmitter's shaft, brushes 1, 2, and 3 come in contact with the shorting ring in a sequence. But brush C is in contact with the shorting ring at all times. One side of the d.c. supply voltage is connected through brush C to the shorting ring. As the shaft is rotated, one side of the supply voltage is connected to the other brushes in a definite order.

The stator of the step motor has six field coils spaced 60° apart. The coils are connected in three groups of two coils each (fig. 2-18), with opposite coils being connected in series. One end of each pair of coils is connected to one of the brushes in the step transmitter. The other end of the coils is connected to the other side of the d.c. supply voltage through a common lead. As the rotor of the step transmitter is turned, the circuits to the field coils in the step motor are energized in a sequence. A rotating stator field is produced in the motor. Since the field's rotation is determined by the brushes in the transmitter, the motor moves in increments, or steps, rather than smoothly.

The rotor of the step motor is made of a mumetal, soft iron, and has four projections in the form of a cross along its length. As the stator field rotates, the field's lines of flux cause the rotor to turn so as to provide a path of least reluctance for the magentic field. Figure 2-19 graphically illustrates the sequence of the steps, while table 2-2 lists the steps and conditions that exist during a complete revolution of the step transmitter. Note that the step motor's rotation is only a quarter of the step transmitter's rotation.

Diodes are used with the step motor as spark suppressors (fig. 2-18). Diodes CR1, CR2, and CR3 act as a short circuit when a voltage is produced opposite to that applied to the coils of the step motor. If the coils of the step motor



STEP A

STEP B

STEP C

STEP D

STEP E

STEP F

166.9

Figure 2-19.—Step-motor action.

Table 2-2.—Step-by-step summary of the action

Steps	Degrees of Transmitter Rotation	Contacts Made	Coils Energized	Position of Rotor Reference Pole
A	0-60	1	1 & 1A	0°
B	60-120	1 & 2	1 & 1A 2 & 2A	15°
C	120-180	2	2 & 2A	30°
D	180-240	2 & 3	2 & 2A 3 & 3A	45°
E	240-300	3	3 & 3A	60°
F	300-360	3 & 1	3 & 3A 1 & 1A	75°

Step A. Coils 1 and 1A are energized, and the nearest rotor pole is drawn into alignment.

Step B. Coils 1 and 1A and 2 and 2A are energized. There are 90° between rotor poles and only 60° between stator-field poles. Therefore, the rotor, in aligning itself so as to present the path of least reluctance, moves midway between the field coils, or a distance of 15 degrees.

Step C. Coils 2 and 2A are energized. The rotor moves an additional 15° to line up its poles with those of the field coils.

Steps D, E, and F. The rotor moves an additional 15° each step in the manner described above.

166.10

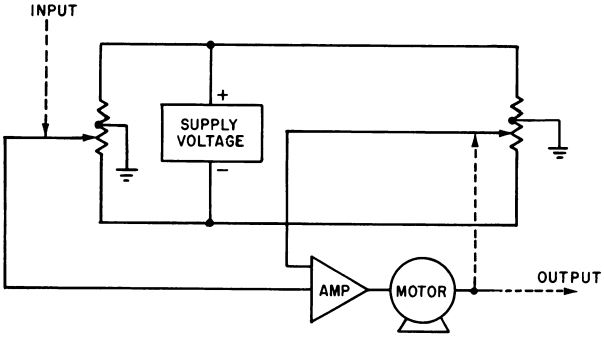
produce a voltage larger than that applied, diodes CR4, CR5, and CR6 appear open.

Step transmission systems are very rugged and seldom malfunction. Occasionally a diode will break down or a spring to the contacts will lose tension. As you can see in figure 2-18, these data transmission devices are relatively simple to maintain and should be no real problem to the FTG.

BALANCED-BRIDGE CIRCUIT

Another data transmission device that you will encounter is the balanced-bridge circuit. Like the step transmission system, the balanced-bridge circuit transmits angular information, but with greater positional accuracy. This circuit consists of two identical potentiometers connected in parallel, with a common source of supply voltage. An amplifier and a motor complete the circuit as shown in figure 2-20.

The wiper arms of the potentiometers are interconnected through an amplifier. If the wiper arms are not at the same potential, a voltage will be felt across the amplifier input. The amount and polarity of the amplifier input voltage controls the amount and direction of the



166.178

Figure 2-20.—Balanced-bridge circuit.

current flow from the amplifier and is determined by the potential difference between the wiper arms.

Assume that we wish to transmit range rate (speed), which is measured in the radar receiver and sent to the remotely located computer. The device that measures range rate positions the wiper arm of the input potentiometer in the radar receiver (fig. 2-20). The range-rate device in the computer (amplifier and motor) will drive the followup (output) potentiometer's wiper arm until there is no current from the amplifier. This condition will occur when each of the two arms is at the same potential and, hence, at the same position on each respective potentiometer. Thus, the followup wiper arm will follow any movement of the input wiper arm.

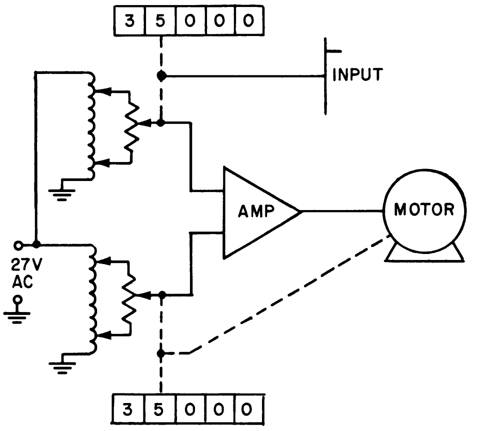
Since range rate can be either negative or positive (inbound or outbound), each potentiometer is grounded at its center. The grounded positions of the potentiometers represent zero range rate. When the wiper arms are in the section of the potentiometers below the grounds, range rate is negative (inbound), while above the grounds, range rate is positive (outbound).

Although the balanced-bridge circuit is more accurate than the step transmission system, it lacks the accuracy to describe a minute position of a very large quantity like the precise range from our ship to a target. This brings us to our next data transmission device—the vernistat.

VERNISTAT

A vernistat transmission system (fig. 2-21) is similar in operation to that of a balanced-bridge system in that the circuit has potentiometer arms in which the voltage in each is balanced, one against the other. The addition of the transformers to the circuit improves the accuracy, which will be brought out in the discussion that follows.

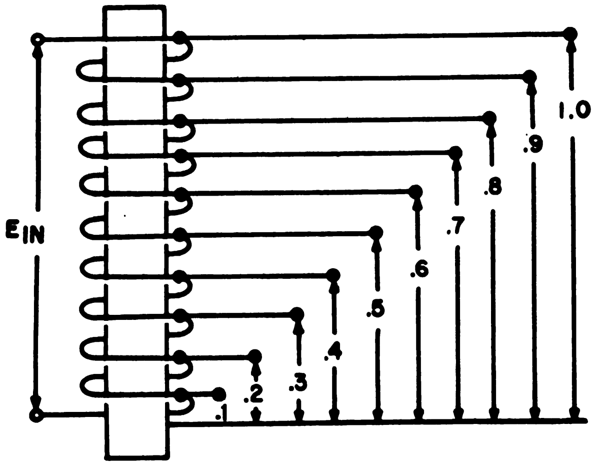
Each vernistat transmission system contains two vernistats. A vernistat consists of a precision autotransformer with a potentiometer in parallel with it. The output voltages from the vernistats are each fed to an amplifier input that controls a motor in a manner similar to the other systems you have just studied. The system is designed so that each voltage tapped from the transmitting vernistat represents a specific value of the quantity being transmitted.



166.15
Figure 2-21.—Basic vernistat transmission system.

The vernistat system is more accurate than the balanced-bridge system because each rotation of the potentiometer shaft picks off only a percentage of the reference voltage instead of the entire reference voltage as in the balanced-bridge circuit.

For example, if the tranformer in figure 2-22 were used in a vernistat, one revolution of the potentiometer would divide the voltage between the bottom of the coil and the first tap. A second revolution would divide the voltage between the second and third taps. The tenth revolution would divide the voltage between the ninth and tenth taps. By looking at figure 2-23, you can see that the output voltage is increasing as each shaft rotation places the potentiometer across a higher set of taps. This means that not until the tenth revolution is the output voltage equal to the reference voltage across the transformer. This is ten times the number of revolutions of the balanced-bridge potentiometer for the same result. The vernistat has increased the accuracy by this same factor of ten.



166.11
Figure 2-22.—Voltage at transformer taps.

The potentiometer has three taps spaced 120° from each other (fig. 2-24). The input shaft moves the wiper of the potentiometer and the potentiometer winding with the three taps so that the section of the potentiometer which is in use will be connected to the proper taps on the transformer. At the same time, the third tap on the potentiometer will be moving towards the next tap on the transformer. The connections between the transformer taps and the potentiometer taps in use are maintained until the third potentiometer tap makes contact with the next transformer tap, in a make-before-break arrangement.

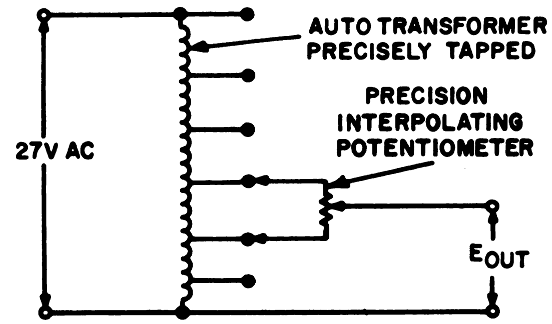


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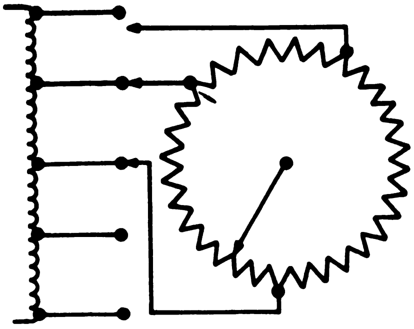
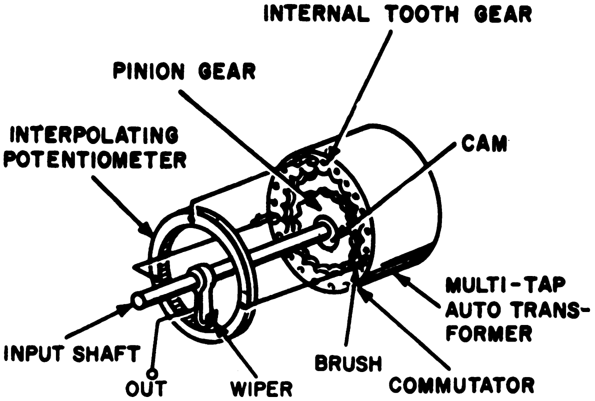
Figure 2-23.—Vernistat basic principles.



166.13
Figure 2-24.—Connections between the auto-transformer and the potentiometer.

The mechanical movement of the potentiometer's wiper arm and winding with the taps must be coordinated with the input quantity. The input shaft rotates the potentiometer wiper arm and an eccentric cam. The motion of the cam is coupled to a 30-tooth pinon gear, (also called a planetary gear), upon which is mounted the potentiometer winding (fig. 2-25). The autotransformer is mounted in a housing containing an internal gear with 31 teeth. The transformer taps, 31 in number, are terminated at the commutator bars. The transformer assembly is fixed with respect to the fire control instrument frame.

The 30-tooth pinion gear is kept in mesh with the 31-tooth internal gear by the eccentric



166.14
Figure 2-25.—Basic vernistat.

cam's rotation with the input shaft. But, since there is a 30- to 31-gear ratio, the actual rotation of the pinion gear with respect to the autotransformer housing for each revolution of the input shaft is one tooth in the opposite direction of the input shaft. The brushes connected to the taps on the potentiometer make contact with the commutator segments. Since there are the same number of commutator segments as there are teeth in the internal gear (31), the brushes are shifted one commutator segment for each revolution of the input shaft. Moving the brushes places the potentiometer across the next set of taps on the autotransformer.

The output of the vernistat can be taken either from between the wiper arm of the potentiometer and one end of the transformer or from between the wiper arm' of the potentiometer and the center tap of the transformer. In the first case, the output operates between zero and maximum, and in the second case, between zero and plus and minus maximum, depending on the direction of the input shaft rotation.

A basic transmission loop using vernistats is shown in figure 2-21. If the output vernistat is not in the same position as the input vernistat there will be a voltage difference between the wipers of the two vernistats. This will produce a voltage at the input of the amplifier. The output of the amplifier is used to drive the motor, which will reposition the remote vernistat to its null position.

Assume that a transmission system has to describe a maximum range of 35,000 yards, and has a maximum of 27-volts a.c. with which to represent this range. This means that a very small fraction of one volt must define many yards of range. This may be accomplished by the vernistat transmission system shown in figure 2-21.

When the vernistat's input shaft is at zero yards, its output voltage is zero volts. As range increases, the vernistat's shaft is turned by the transmitting instrument that drives it. As you have just seen, the potentiometer functions to smooth the changing output voltage. Thus, as the input quantity (range) increases, the output voltage changes smoothly and linearly, resulting in an accurate description of range even with a low maximum voltage (27 volts) and a long maximum range (35,000 yards). These values, of course, are examples and not necessarily the values you will find in any given system.

Vernistat Maintenance

A vernistat should never have a large current applied to it. When maintenance tests are held, a standard multimeter should not be used since the d.c. voltages would cause large currents to flow, which could damage the vernistat. The vernistat may be tested by applying the proper voltage and taking a reading with an oscilloscope or a vtvm. The proper voltage is the reference voltage of the instrument and will be listed in the system OP.

TACHOMETER GENERATORS

The data transmission systems that we have discussed so far are used to transmit positions. In some fire control applications, the rate of movement is of greater importance than physical displacement or specific position. Rates are known as velocities, and velocity signals must be transmitted rather than position signals.

In figure 2-26, a tachometer generator, commonly called "tach" for short, produces an output voltage whose magnitude is proportional to the number of revolutions its rotor makes per unit of time (rpm). The phase or polarity of the output voltage is determined by the direction the rotor is turned. Hence, a tach's output/voltage is representative of the speed and the direction of the rotor's motion, in other words, its velocity.

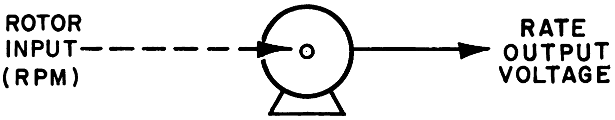


Figure 2-26.—Tachometer generator.

An example of a tachometer generator transmission system is shown in figure 2-27. Assume that we desire to transmit the angular velocity of a moving aircraft as it travels across the sky, so that we may keep the radar antenna on target. A fire control instrument which measures this velocity turns the input shaft and produces a voltage from the signal tach of a given magnitude and polarity. This voltage is felt at the amplifier, which attempts to drive the motor at full speed and in the direction controlled by the polarity. But as the motor, which is geared to the output load and response tach, comes up to speed, it causes the output tach to produce a voltage that opposes the signal tach's voltage. The difference between the two tach voltages at the amplifier input is such that the amplifier output will continue to drive the motor at the input rate—the velocity representing that of the airplane. If the signal tach were to receive an increased velocity signal, the effective amplifier input would be increased, and the motor would drive at the higher rate.

Tach Construction and Principles

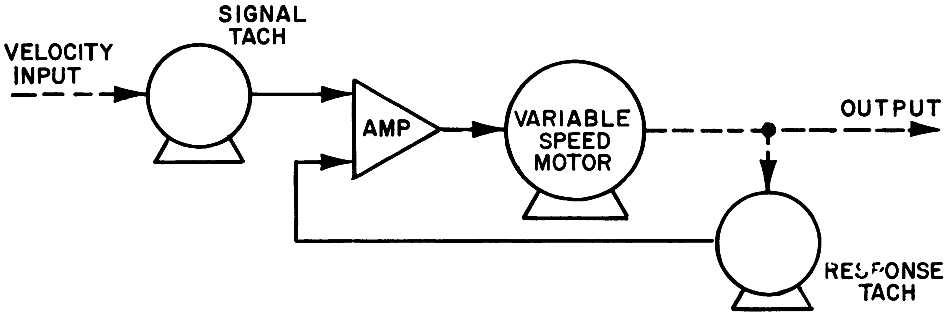
There are two types of tachs, a.c. and d.c. The type that is used in a given data transmission system depends upon the amplifier and motor used with it, and what the transmission system was designed to control. Normally, light output loads with minor velocity changes would use an a.c. tach, and heavy outputs loads with widely varying velocities would use a d.c. tach.

A.C. TACHOMETER GENERATOR.—The a.c. tach shown in figure 2-28 has two stator windings displaced 90° from each other, and an aluminum or copper-cup rotor (called a drag cup). The drag-cup rotor is mounted so that it is free to rotate around a stationary soft-iron magnetic core. One stator winding, called the reference or primary winding is energized by a reference a.c. source. The other stator winding is the tach's output or secondary winding.

The tach's operation is based on transformer principles. The reference voltage applied to the primary winding creates a magnetic field. If the drag-cup rotor is not being driven, the magnetic field is at right angles to the secondary winding (fig. 2-28A).

When the rotor of the tach is turned, it distorts the magnetic field so that it is no longer 90 electrical degrees from the secondary winding. Flux linkage is created with the secondary winding and a voltage is induced (fig. 2-28B, C). The amount the magnetic field will be disturbed is determined by the angular velocity of the rotor. Therefore, the magnitude of the voltage induced in the secondary winding is proportional to the rotor's velocity.

The direction of the magnetic field's distortion is determined by the direction of the rotor's motion. If the rotor is turned in one direction the lines of flux will cut the secondary



166.180

Figure 2-27.—Tachometer generator transmission system.

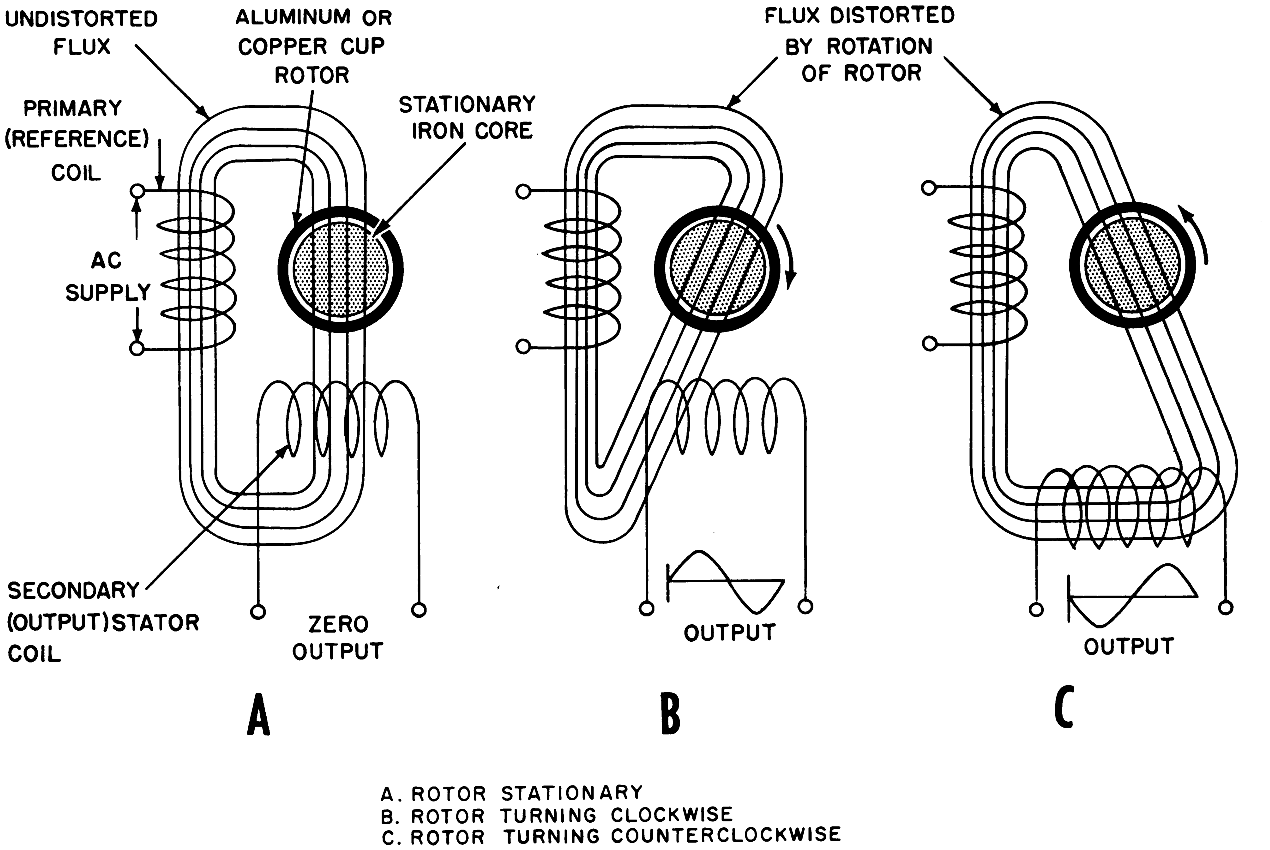

UNDISTORTED FLUX
ALUMINUM OR COPPER CUP ROTOR
PRIMARY (REFERENCE) COIL
STATIONARY IRON CORE
AC SUPPLY
SECONDARY (OUTPUT) STATOR COIL
ZERO OUTPUT
FLUX DISTORTED BY ROTATION OF ROTOR
OUTPUT
OUTPUT
A
B
C
A. ROTOR STATIONARY
B. ROTOR TURNING CLOCKWISE
C. ROTOR TURNING COUNTERCLOCKWISE
55.40

Figure 2-28.—A.c.-drag-cup rate generator.

winding in one direction. If the motion of the rotor is reversed, the lines of flux will cut the secondary winding in the opposite direction. Therefore, the phase of the voltage induced in the secondary winding, measured with respect to the phase of the supply voltage, is determined by the direction of the rotor's motion.

The frequency of the tach's output voltage is the same as the frequency of the reference voltage. This is reasonable, since the magnetic field produced by the primary winding fluctuates at the supply's frequency. The output voltage is generated by the alternating flux field cutting the secondary winding. Therefore, the output voltage must have the same frequency as the supply voltage.

D.C. TACHOMETER GENERATOR.—In principle, the d.c. tach is basically a d.c. generator. The difference is that a d.c. tach uses permanent magnets to create the magnetic lines of force that are cut by the rotor winding. Permanent magnets are used because the high power available from generators using stator windings is not needed in tachometer generator applications.

The d.c. tach, unlike the a.c. tach, has a wound rotor. As the rotor is driven by the velocity input, a voltage is induced that is proportional to the rotor's angular velocity. This voltage is fed to a d.c. amplifier, and the motor speed is controlled in the same manner as with the a.c. system. One advantage of this system is that a d.c. motor is used. You will remember that the speed of a d.c. motor is more easily changed over a greater range than is the speed of an a.c. motor.

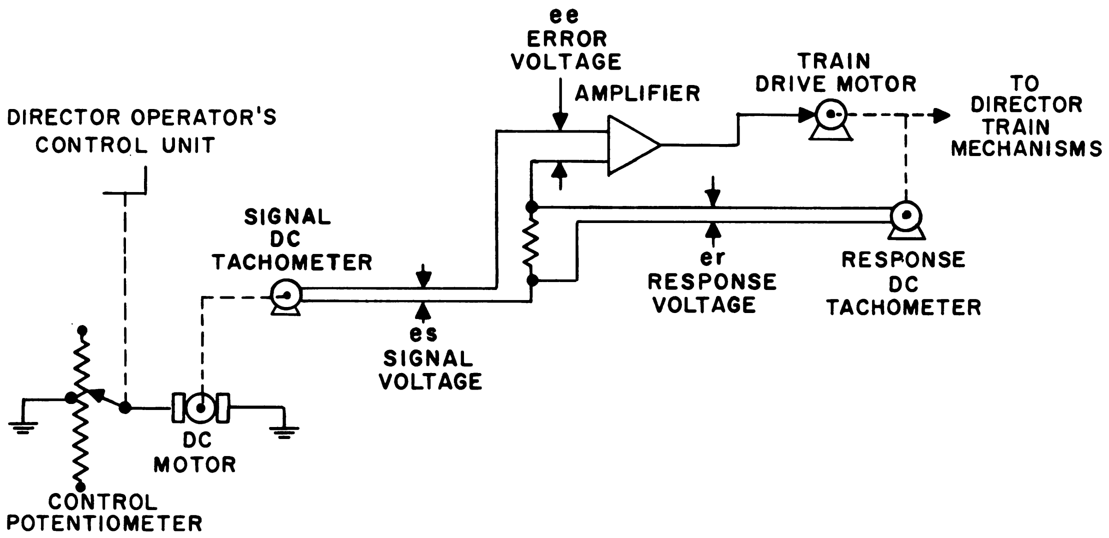
Velocity Signal Transmission System

As a practical application of what we have just learned, let's use a director train power drive. Our discussion will be limited to the signal transmission system; we will cover the director drive later. Assume the director has established the position of a moving target which has a constant bearing rate. We will also assume that the director operator is using the controls to maintain the director telescope's line of sight on target.

Figure 2-29 is a simplified diagram of this velocity data transmission circuit. The director operator moves the control which positions the wiper of a potentiometer. The potentiometer controls the armature current of a small d.c. motor, hence the motor's speed. The motor's rotation can be reversed by moving the potentiometer's wiper to the opposite side of the grounded center tap. The motor drives a permanent magnet d.c. tachometer. The output of the tach is a d.c. voltage (es), whose magnitude is proportional to the ordered velocity of the director and whose polarity indicates the ordered direction of the train motion. This voltage is applied to the director train amplifier.

Circuits in the amplifier determine if the input signal (ee) is a train right or train left order by its polarity. The output of the amplifier is a d.c. voltage whose magnitude is proportional to the input signal and whose polarity is determined by the signal. The output voltage is the input to the train drive motor. The drive motor moves the director train mechanisms at a rate proportional to the magnitude of the input voltage and in the direction determined by its polarity.

Mechanically coupled to the train drive is a response d.c. tach whose output voltage is a measure of the director's train rate. The reponse voltage (er) is applied across a resistor in the signal circuit in such a manner as to oppose the signal voltage. When the response voltage is equal and opposite to the signal voltage, the director train is moving at the ordered rate. The train system has been greatly simplified for this discussion. But it can be seen that the signal circuits are transmitting velocity data between locations.



166.16

Figure 2-29.—Simplified train drive velocity signal circuit.

FIRE CONTROL SWITCHBOARDS

Fire control data transmission devices that we have studied, and other FC instruments, can be controlled at the FC switchboard. The reference or supply voltages to these devices can be energized (turned on) or deenergized (turned off) from the switchboard. Also, the transmitter of a data transmission device can be switched to control one or more combinations of receivers. While the switchboard itself does not actually transmit data, you can readily see that it has an important function in the transmission of data.

Fire control systems receive their electrical power from distribution panels and controllers located in the IC room, or from the main electrical boards in the engineering spaces. Most of this power is sent to the FC switchboard for further distribution to units in the FC system. This provides a central station from which the electrical arrangement of the FC system can be controlled.

In the simplified diagram (fig. 2-30), we have two gun directors and one computer. The top switches energize the director train circuits and connect the train signals to the switchboard. The bottom switch connects the computer's director train receivers to the director. Thus, through the switchboard, we can connect the computer to either director. Since the interconnections between system units can be changed, the flexibility of the FC system is greatly increased.

SWITCHBOARD DEVICES

A fire control switchboard is shown in figure 2-31. The rotary switches transfer control of certain circuits from one station to another. These switches permit the isolation of various portions of the FC system and are referred to as action-cutout (aco) switches. The individual rotary switches are installed in separate, boxlike housings as shown in figure 2-32A and B. The

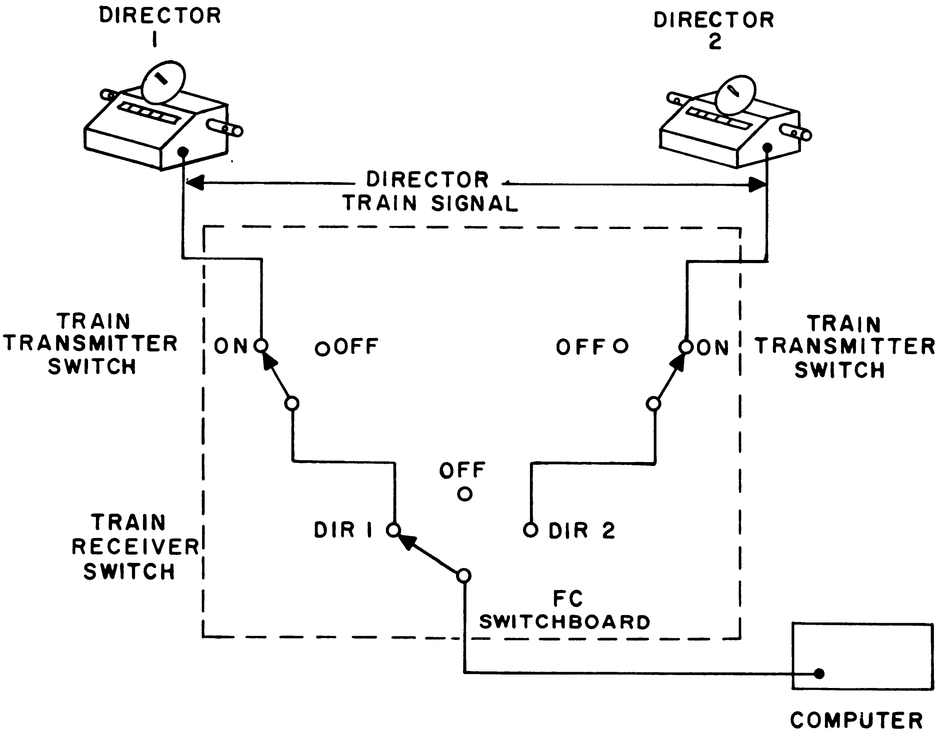


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Figure 2-30.—Director train switches.

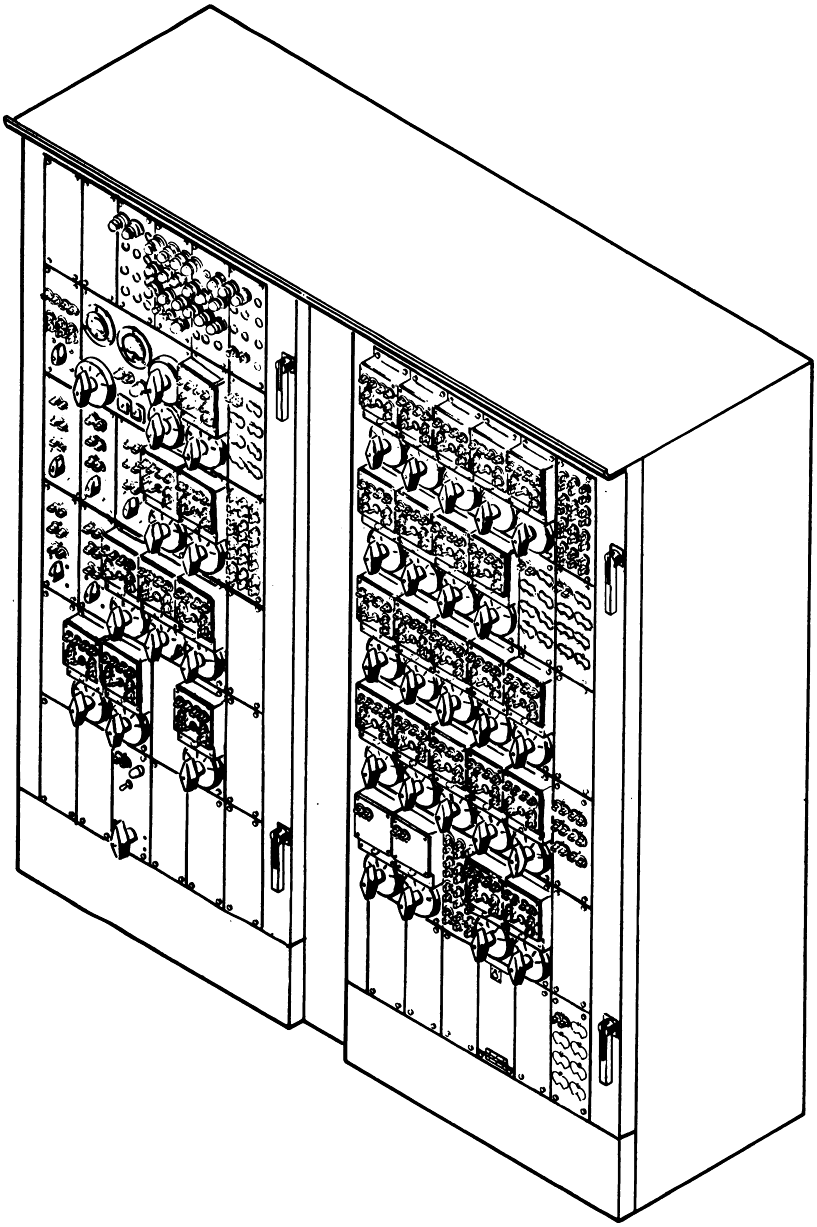

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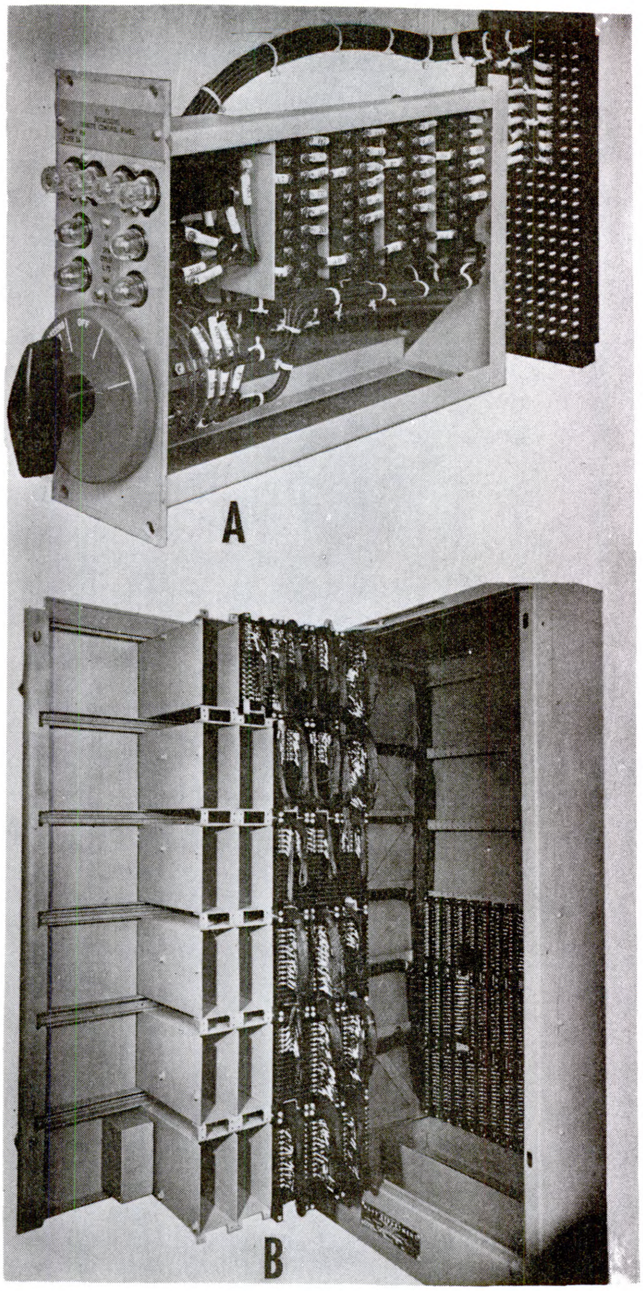
Figure 2-31.—Fire control switchboard.

switchboard is normally located in the plotting room of the gun fire control system.

Junction Rotary Switch

Often referred to as a JR switch, this aco type of switch is used to energize or interconnect data transmission devices. In applications that require infrequent switching, such as setting up the GFCS in a predetermined mode of operation, a manually operated JR switch is normally used. This type of switch is shown in figure 2-33. An operator does all of the work.



55.316

Figure 2-32.—ACO switch and switchboard. (A) Action cutout unit; (B) Rear view, door open.

In other applications, where switching is rapid and more frequent, a remotely operated junction rotary switch is often used. Figure 2-34 shows this type, commonly referred to as AJR—automatic junction rotary. The function of the AJR switch is identical to that of the JR switch. The difference is that the AJR switch has a motor drive unit that is remotely controlled by additional circuitry, and the constant attention of an operator is not required.

Snap Switch

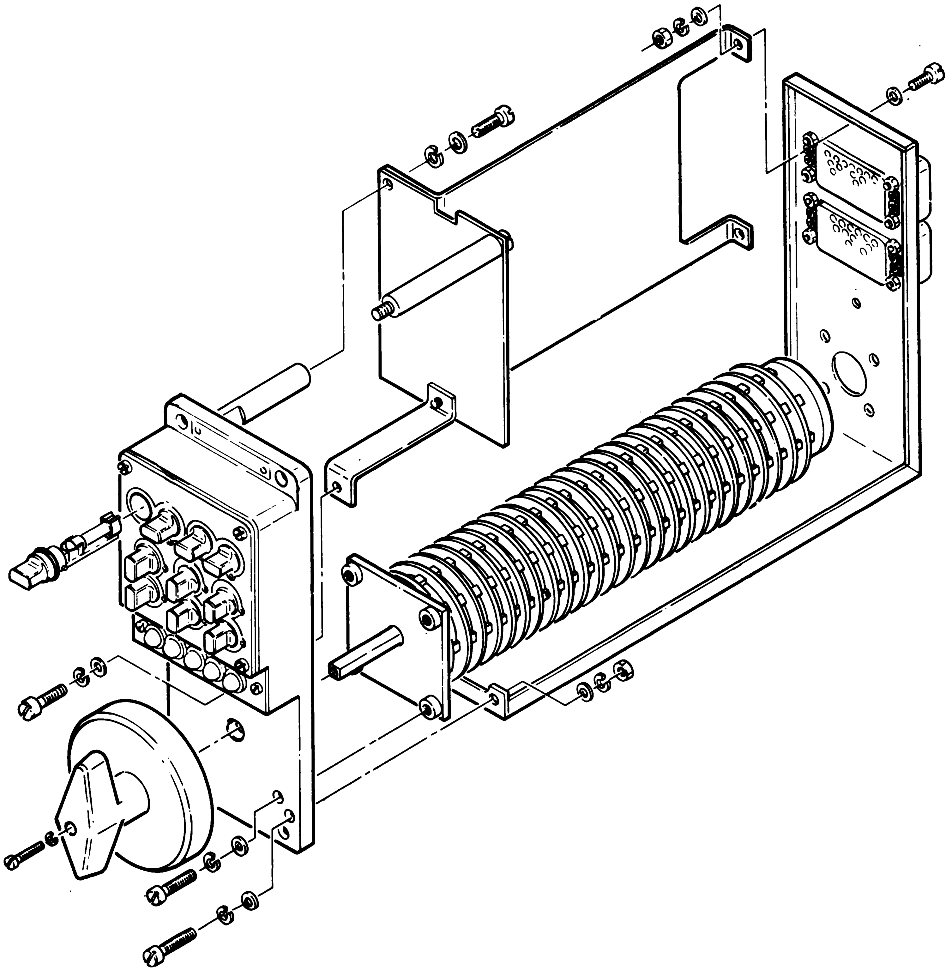
The snap switch (fig. 2-35) is used where current requirements are high, or where only a few circuits are to be switched. Normally these are used to energize remote units of the GFCS.

Switchboard Indicators

As you can see from figure 2-31, the switchboard has numerous indicator lights and dials. These show such things as switch position, power available, overloads, and blown fuses. The location of these indicators (fig. 2-36 and 2-37) and what they actually indicate will differ from system to system. You will have to study an actual switchboard and/or applicable technical manual in order to get specific information on any given system. At this point, it is enough to know that these indicators exist and that their proper use will aid you in both operating and maintaining the system.

Switchboard Maintenance

Normal maintenance requires that you replace specific defective parts. As you have seen in the illustrations of switchboards and switchboard components, switches, panels, smaller components, and various pieces of hardware are replaceable. However, as in all Navy maintenance, you should be aware that wartime maintenance will more than likely require that technicians repair many of the components that in peacetime would be replaced. Your ability to repair or to go more deeply into your equipment could, in time of war, become critical or even vital to the mission of your ship.



166.181

Figure 2-33.—Manually operated JR switch panel assembly—exploded view.

SUMMARY

This chapter has provided basic information on the various types of data-transmission devices found in Navy fire control systems. Advantages and disadvantages along with similarities and differences have been stressed. An attempt has been made to familiarize you with the environment in which these devices are applied and with the maintenance problems you will have relative to them.

The Nonresident Career Course (NRCC) assignment for this chapter, and all others, is printed in the back of this book. Participating in these assignments will provide the following for you:

1. An objective measure of what you have learned and where you need future study.
2. One method of completing this "mandatory" rate training manual.
3. An additional learning tool that can help you retain what you have learned and make time spent on restudy of unlearned material more meaningful.

Even if you are not taking the course for credit, working the assignments will be of benefit to you.

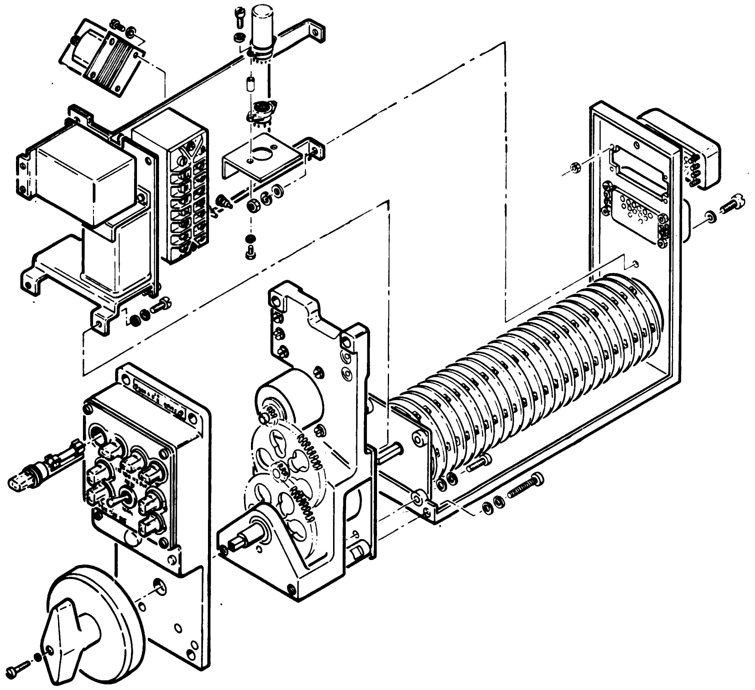


Figure 2-34.–Remotely operated JR switch panel assembly–exploded view. **166.182**

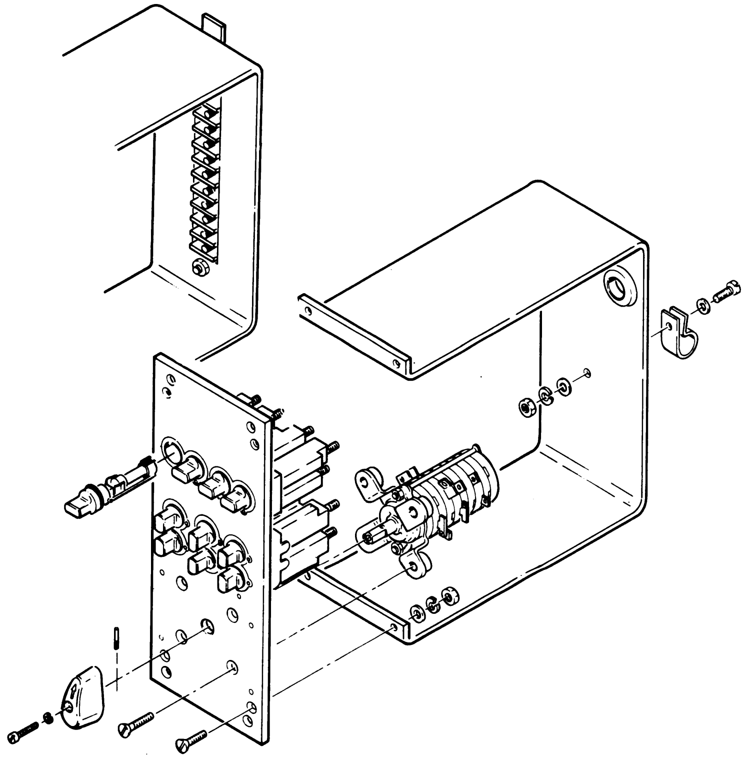


Figure 2-35.–Snap switch panel assembly–exploded view. **166.183**

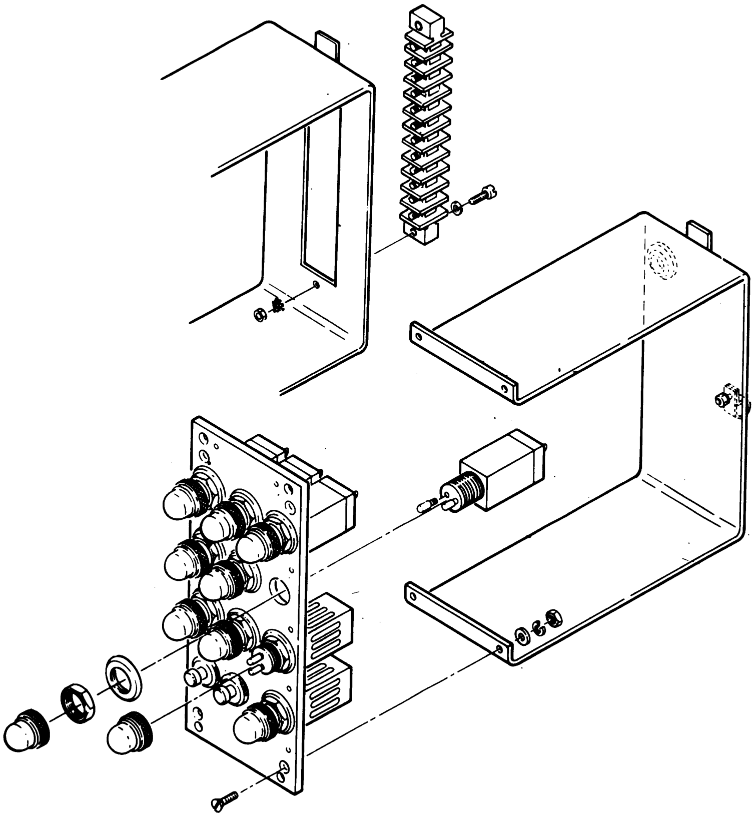


Figure 2-36.—Indicator panel assembly—exploded view. 166.184

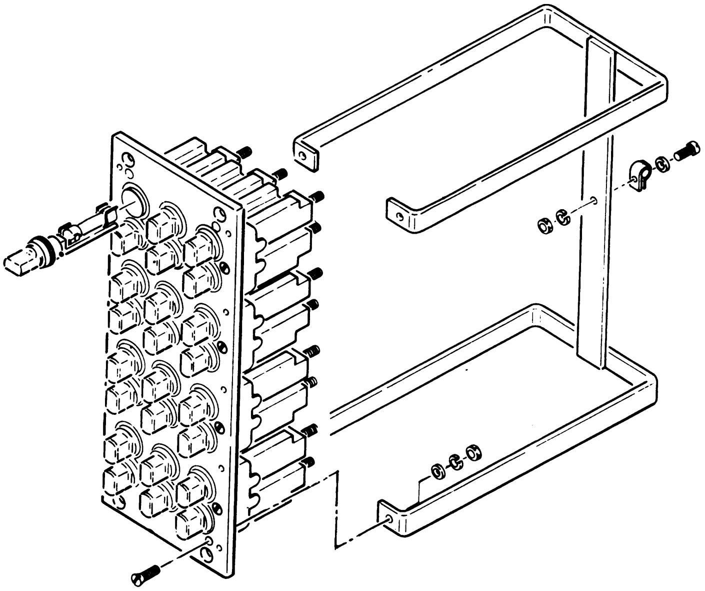


Figure 2-37.—Overflow fuse panel assembly—exploded view. 166.185

CHAPTER 3

SERVOMECHANISMS

INTRODUCTION

A servomechanism, often called a servo for short, is a group of components (both mechanical and electrical) that produces a strong mechanical output from a relatively weak input signal, that is, one that is too small to drive a desired load. In other words, a servo is used to position or control a load in response to an input signal capable of supplying only a very small amount of power. The servo operates to reduce to zero any difference that may exist between the actual and the desired positions of the load.

You will remember, from the chapter on data transmission, that data is transmitted throughout the fire control system anywhere from a few feet to several hundred feet. Some locations are remote and not attended by FTs. Many of these data transmission devices end up with a servomechanism to drive the load. This load could be a radar antenna, a gun mount, a device within the computer, or any of a number of other devices.

Every major unit of the gun fire control system employs servos to some extent, as shown by the shaded areas in figure 3-1. For this reason, it is essential that you have a working knowledge of servos. As a member of the FT gang, you will be expected to test, align, troubleshoot, and repair servos.

This chapter will be limited to a discussion of the types of servos found in fire control equipment. It is assumed that you have had some background in the theory and operation of servos. One source of this information is the appropriate module in the *Navy Electricity and Electronics Training Series, NEETS,* previously mentioned.

ELEMENTARY SERVO OVERVIEW

The elementary servo shown in the block diagram in figure 3-2 has all of the characteristics of an operational servo. The input to the error detector is an order signal which indicates the desired action of the load. The feedback signal indicates the present position of the load. The output of the error detector is known as the error signal, the difference between the input and feedback signals, and represents the amount the load must be driven to conform to the order signal. The error signal is amplified in the power amplifier and is then used to drive the servomotor. As the motor drives the load in the desired direction, the feedback to the error detector changes, and the error signal is reduced. This continues until, very shortly, the feedback completely nulls the input signal. At this point the error signal has been reduced to zero, indicating the load has moved in accordance with the original order signal. You will note that this is the same process of order and response that was described in the chapter on data transmission.

A real, operational servo may be electrical, mechanical or hydraulic. No matter how the servo is constructed, it will have components that perform functions similar to those in our elementary servo described above.

SYSTEM CONCEPT

Because we will be presenting the functional sections of a servo one at a time, it is important that you keep in mind that these components must work together to provide control of a heavy or isolated load. You should not consider

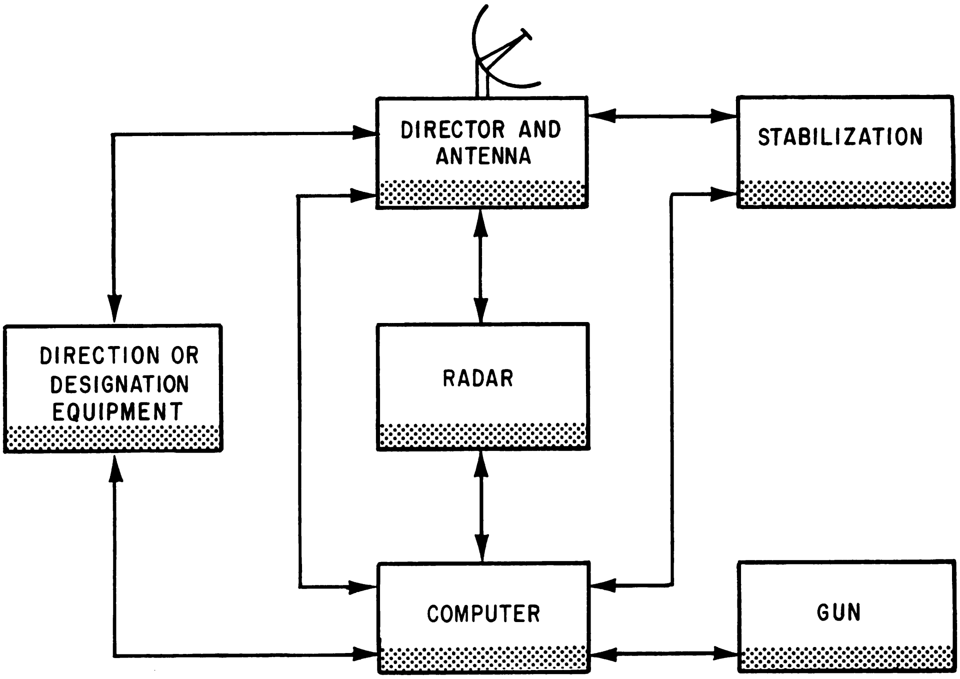


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Figure 3-1.—Servos (shaded areas) are used throughout the gun fire control system.

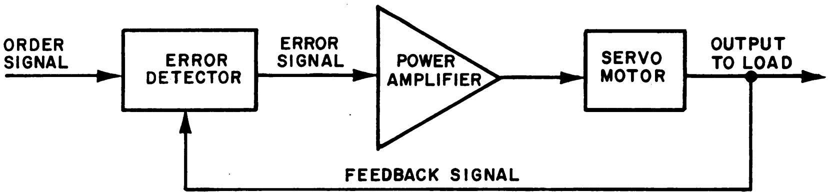

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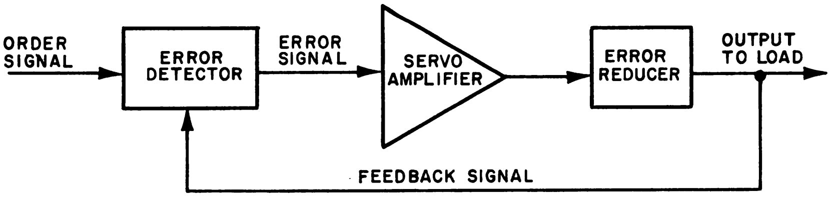
Figure 3-2.—Block diagram of an elementary servo.

them as individual components. They all function in a system in which each part has its effect on the other parts. Together, the components of a servo measure, transmit, compare, amplify, and control. Separately, they have no function in fire control.

SERVO FUNCTIONAL SECTIONS

The major components of a servo are the error detector, servoamplifier, and error reducer, as shown in figure 3-3. The error detector (in an electromechanical servo) may be a potentiometer, synchro control transformer, or other electrical device which functions to provide an output signal corresponding to the magnitude and direction of the input. The amplifier may be any one or combination of various types of electron tubes, transistors, or magnetic servoamplifiers. The error reducer (sometimes referred to as the prime mover) is usually an a.c. or d.c. servomotor which drives the output load.



166.190

Figure 3-3.—Major components of a servosystem.

ERROR DETECTORS

The function of any error detector, regardless of type, is to receive an order signal and a feedback signal, compute the algebraic sum of these signals, and feed the result of this computation as an error signal, to the servoamplifier.

The order and feedback signals may be either electrical or mechanical, depending on the requirements of the type of error detector in the servo. The error signal to the servoamplifier is electrical. Common error detectors are synchro control transformers, potentiometers, summing networks, and E transformers. Let's take a brief look at them.

CT Error Detector

A servo using a CT as an error detector is shown in figure 3-4. The "order" (input) positions the CX rotor mechanically. The CX then provides the order signal to the CT error detector. The CT, in turn, compares the order signal with the actual position of the load and provides an error-signal output from its rotor to the servoamplifier. The servoamplifier output supplies the control field of an a.c. servomotor with voltage of the proper phase so as to cause the motor to drive the load in the direction required by the original "order". As the load is driven, the mechanical feedback from the error reducer also drives the CT rotor into correspondence, its null position, which reduces the error signal to zero, stops the motion, and indicates that the order has been obeyed.

Potentiometer Error Detector

A basic, closed-loop servosystem using a balanced potentiometer as an error detector is shown in figure 3-5.

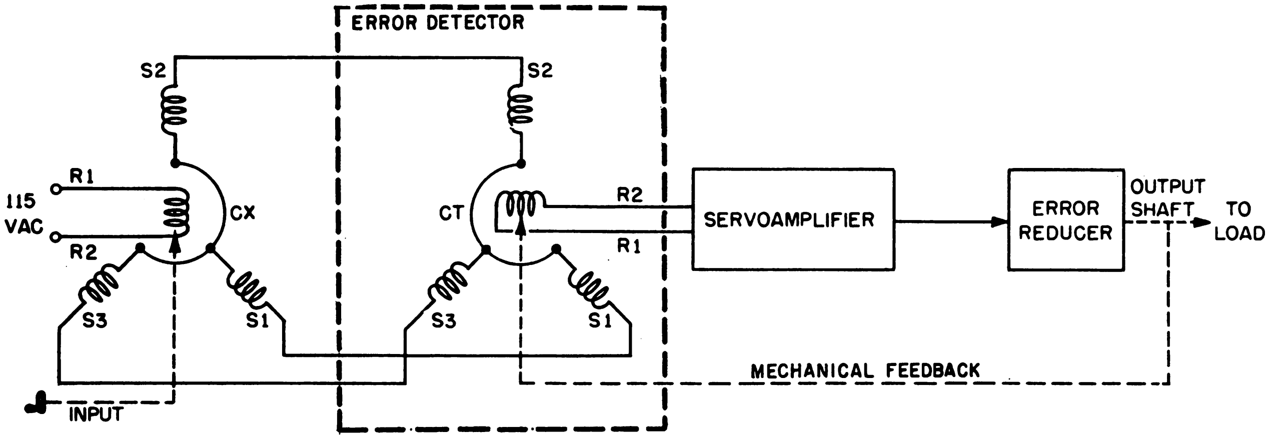


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Figure 3-4.—The CT as an error detector.

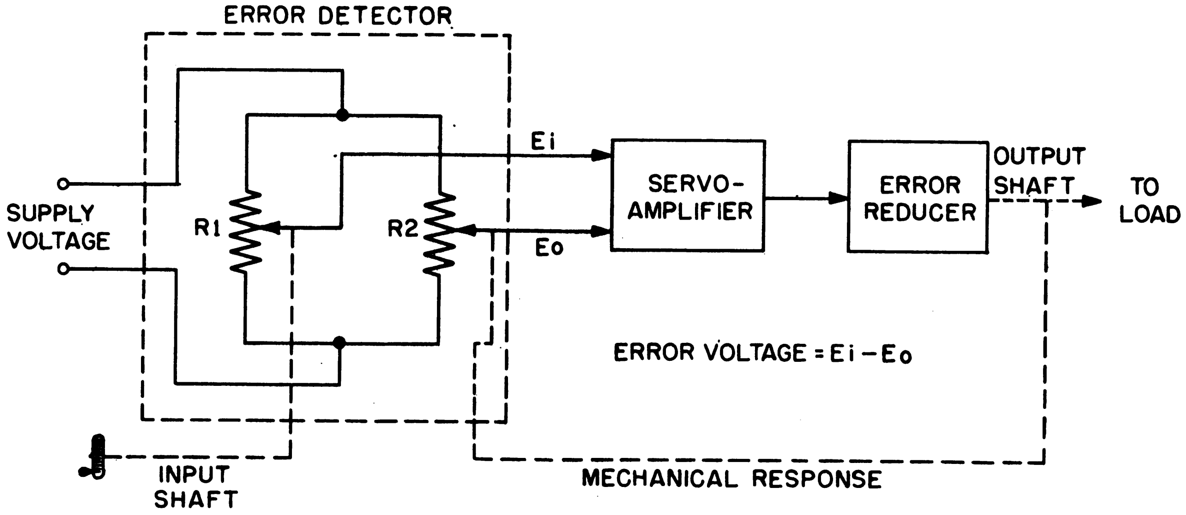

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Figure 3-5.—Balanced potentiometer as an error detector.

The command input shaft is mechanically linked to R1, and the load is mechanically linked to R2. An electrical supply voltage is applied across both potentiometers.

When the input and output shafts are in the same angular position, they are in correspondence, and there is no output error voltage. As the input shaft is rotated, moving the wiper contact of R1, an error voltage is applied to the servoamplifier. The error voltage is the difference between the voltages at the wiper contacts of R1 and R2, Ei and Eo, respectively. The output of the amplifier causes the motor to rotate the load and the wiper contact of R2 until Eo equals Ei. The error has been detected in a different way, but the system results are the same.

Summing Network Error Detector

Summing networks (fig. 3-6) are used as error detectors in servo applications where the order signal is electrical. In figure 3-6A, the order signal (E1) is applied to resistor R1 of the summing network. This voltage is then felt by the servoamplifier which causes the error reducer (servomotor) to rotate the load and the wiper arm of the feedback potentiometer. This rotation continues until the wiper arm picks off a voltage (Ef) that is equal in amplitude and opposite in polarity to E1. Because of this, the error voltage from the summing network to the servoamplifier is reduced to zero, and the error reducer stops driving the load.

There are applications in fire control equipment where two or more order signals must drive the same servo. The idea here is that the servo output must be proportional to the algebraic sum of the order signals. In figure 3-6B, if two order signals (E1 and E2) are applied to the network, the network will provide an error voltage output proportional to the algebraic sum of the two signals. As stated earlier, the servomotor, in driving the load, also drives a feedback potentiometer which supplies the voltage to feedback resistor Rf to null the order signals, hence the error signal.

There are more types of error detectors, but this manual is not large enough to discuss them all. By now, you should have a basic understanding of what an error detector is, and how it works. The type of error detector that is chosen for a given servo depends upon its compatability with the input (order) signal and the feedback signal.

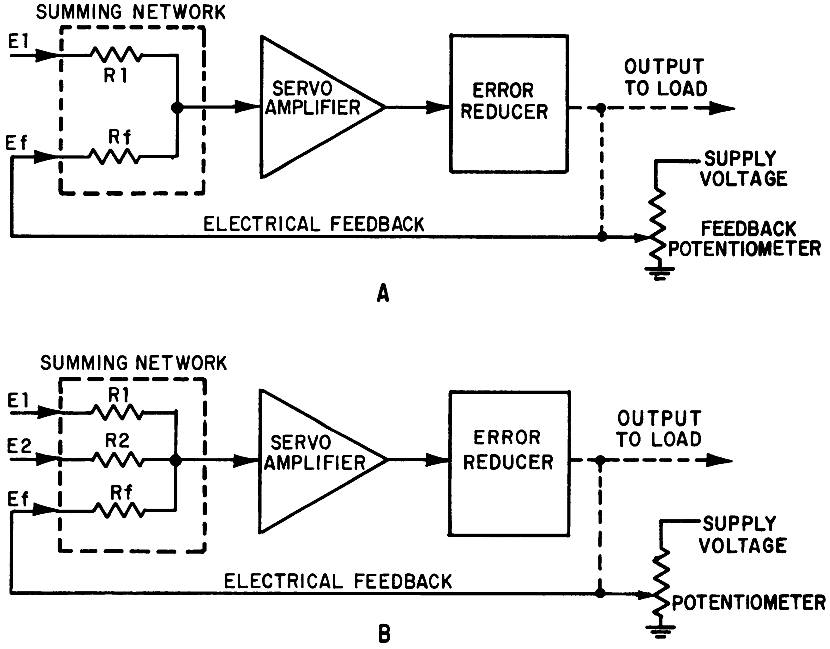

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Figure 3-6.—Summing network as an error detector.

SERVOAMPLIFIER

In addition to amplifying the error signal sufficiently to drive the servomotor, servoamplifiers, in some cases, convert the error signal from a.c. to d.c., or vice versa. They also include circuitry necessary to obtain stable, fast, and accurate servo operation (which will be discussed later in this chapter). Both a.c. and d.c. amplifiers are used as servoamplifiers. However, the a.c. amplifier is more commonly used because of the problems associated with d.c. amplifiers. These problems include drift (a variation in output voltage with no change in input), and the necessity for special bias voltages in cascaded stages.

Desirable characteristics in servoamplifiers include a flat gain versus frequency response for a frequency well beyond the frequency range that is used, a minimum amount of phase shift with a change in input signal, a low output impedance, and a low noise level.

As the servosystem is a null-seeking system, linearity is not nearly as important in servoamplifiers as in audio amplifiers. Also, the servomotor, or other type of error reducer driven by the servoamplifier, can withstand a much higher level of distortion than the human ear. Thus, servoamplifiers are often driven far beyond the limit of distortionless output.

Servoamplifiers generally have a voltage amplifier or preamplifier stage followed by a power amplifier stage. The voltage amplifier amplifies the error signal without changing its electrical characteristics and the output of the power amplifier supplies the servomotor. The amplifier may also include a modulator to convert a d.c. signal into an equivalent a.c. signal, or a demodulator to convert an a.c. signal into an equivalent d.c. signal.

ERROR REDUCER

The function of the error reducer is to drive the load to its ordered position and at the same time drive the error detector to its null or no-signal position. The error reducer is a powerful device that does the actual work of the servo.

Both a.c. and d.c. motors are used as error reducers, depending upon the requirements of the servo. Servos that must position heavy loads over a wide speed range use d.c. motors, whereas the lightly loaded and relatively constant-speed servos use a.c. motors.

Hydraulic servos are sometimes used in fire control systems. Hydraulic power devices, such as motors and associated control valves, have a much faster response than the best electric motors. They are also very accurate and well adapted to heavy loads.

TYPES OF SERVOS

As mentioned previously, the input (order) signal to a servo is weak. A servo increases the power of this weak signal sufficiently to drive a desired load. In this topic, we will discuss three types of servos that are used in fire control equipment. They are electric servos, electromechanical servos, and electrohydraulic servos.

The type of servo used in a specific application is determined by the load it has to drive. This load could be as light as the arm of a potentiometer or as heavy as a large gun director that weighs several tons.

Electric servos are used with light loads. This type does not need an amplifier to boost the power to the error reducer. The necessary increase in power comes directly from an a.c. or d.c. power source, which will be explained shortly.

If the load is larger and variable in speed, the servo must have an amplifier to increase the signal power supplied to the error reducer. Most servos in fire control equipment are this type, called electromechanical. The electromechanical servo has an amplifier, and an electric motor which is used as an error reducer.

There are a few electrohydraulic servos in fire control. In the hydraulic servos, the input signal is amplified in an electronic ampifier. The amplified signal controls an electric device which, in turn, controls the hydraulic power system. This type of servo is used where very high power is required to drive the load.

Each type of servo has advantages. The electric servo is the simplest. The electromechanical servo is more flexible and can provide positive control at variable speeds. Hydraulic servos are used with heavy loads subject to sudden and drastic changes, and cannot be backed down by the load.

Now, let's discuss each type in a little more detail.

ELECTRIC SERVO

In an electric servo (fig. 3-7), a bearing-mounted synchro receiver (error detector) controls a set of electrical contacts. These contacts, in turn, control the supply voltage (power amplification) to a servomotor (error reducer).

When the synchro receives an order signal, the rotor attempts to respond by rotating to the new position. This attempted rotation closes the contacts and causes the servomotor to drive in the desired direction. As the servomotor drives the load, it also rotates the stator of the bearing-mounted synchro. This rotation continues until the synchro stator is aligned with the rotor at the null position. As the synchro reaches its null position, the rotor loses its torque (at correspondence), the contacts open, and the servomotor stops driving. At this time, the load has been driven to the new, desired location. A bearing-mounted synchro receiver is shown in figure 3-8 to refresh your memory. The order signal is the mechanical movement of the rotor. The feedback is also mechanical, and

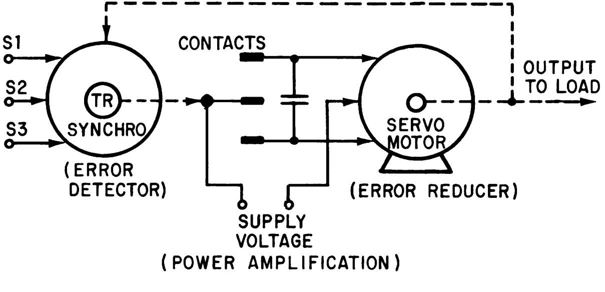

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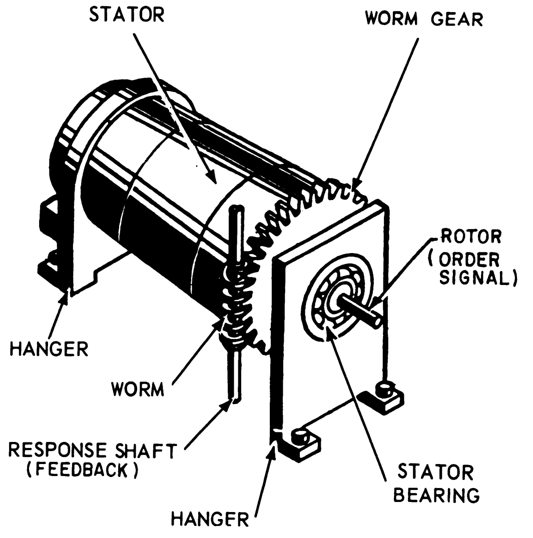
Figure 3-7.—Electric servo.



12.171

Figure 3-8.—Bearing-mounted synchro receiver.

drives the worm and worm gear to null the synchro.

In figure 3-7, the servomotor is a 115-volt a.c. motor with split-phase operation. The capacitor in the circuit shifts the phase of the voltage to one of the motor's windings. The contacts determine which winding will receive the shifted voltage and hence which way the motor will drive. One side of the line voltage is connected to the common point between the stator windings of the motor. The other side of the supply is connected to the center contact which is connected to the rotor of the synchro. An order signal to the synchro will cause the center contact to rotate and to complete the circuit to one or the other of the outer contacts. Note that either of the outer contacts will complete the circuit to the motor, but by separate paths. The capacitor will be in series with one of the motor's windings. The selected winding is determined by the contacts, hence by the synchro order signal. The capacitor will shift the phase relationship of the voltage applied to the other windings. The motor will drive until response opens the contacts.

The advantage of an electric servo is its simplicity. Its disadvantages are lack of speed control and limited current-carrying capacity. The servo is either at correspondence (null) or driving, and, thus, is strictly a position control. The low torque of the synchro limits the size of the contacts and, hence, their current-carrying capacity. This, in turn, limits this type of servo to light loads.

ELECTROMECHANICAL SERVO

The position servo shown in figure 3-9 is an example of an electromechanical servo. This particular servo employs a synchro transmission system for the transmission of radar range information from a fire control radar range unit to a distantly located computer range servo.

Assume that the fire control radar has measured target range at 10,000 yards. The CX in the radar (fig. 3-9) will transmit range to the CT in the computer. Assume that the range servo in the computer is at 9,000 yards. Hence the CT, the error detector, will not be at its null position. The error signal from the CT will be proportional to the 1,000 yards of displacement between the ordered position and the actual position of range in the computer. The servomotor will drive until the rotor of the CT is at its null position, which represents 10,000 yards in range.

The electromechanical servo just presented is only one example of an electromechanical servo. Other devices such as potentiometers and resolvers can cause a servo to be classified as electromechanical. These devices convert mechanical energy to electrical energy, and are used as error detectors and feedback devices. Because they merely convert energy, a servoamplifier must be used with this type of servo to develop the power necessary to move the load.

The theory of electromechanical servos is identical to that of all closed-loop servos. Response from the output is fed back to the input to null the error signal. The amplifier has a large power source which is controlled by the low-powered order signal. The amplifier can detect the direction in which the load must be moved by the phase of polarity of the error signal. The amplitude of the error signal determines the amount of the velocity of the servo motor's output.

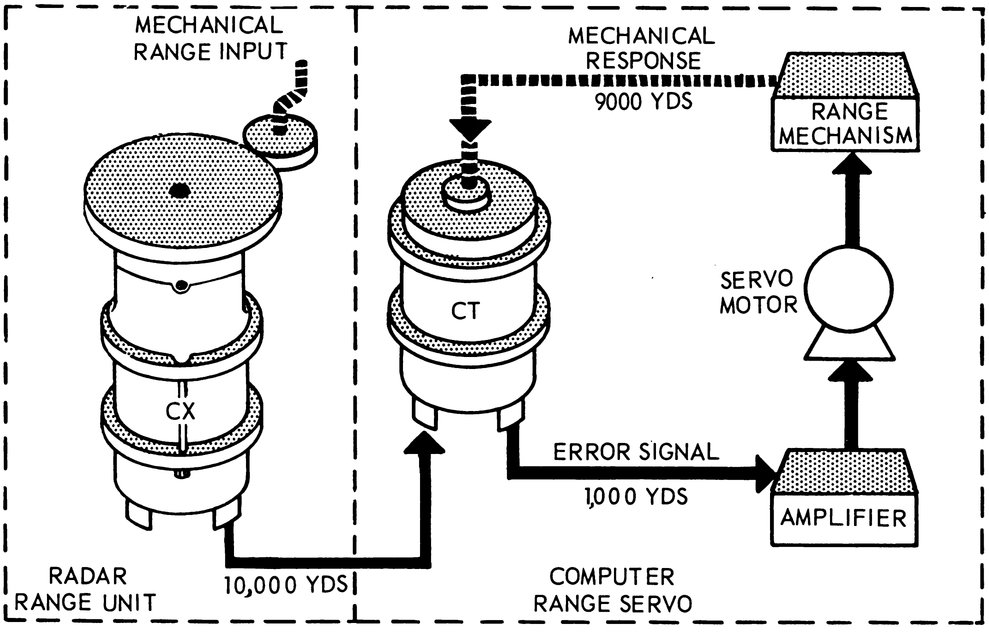


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Figure 3-9.—Position servo.

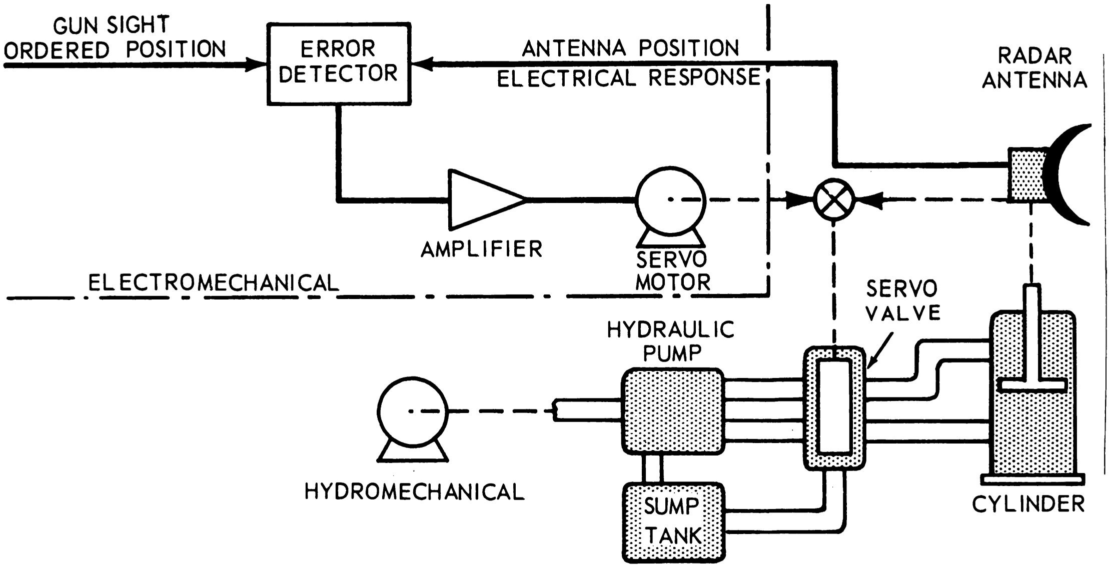
ELECTROHYDRAULIC SERVO

Figure 3-10 is a simplified block diagram of a radar antenna position system that uses an electrohydraulic servo. The electrical section of the drive is a typical electromechanical servo. The output of this section, however, does not move the antenna directly, but is used to control the hydraulic section of the servo. The servomotor controls the movement of the servovalve through a mechanical differential linkage.

The servovalve governs the flow of the high-pressure hydraulic oil to the antenna positioning cylinder. In its neutral position, the servovalve blocks the flow of hydraulic oil to the cylinder. The high-pressure oil trapped in the upper and lower chambers of the cylinder forms a hydraulic lock on the piston. The piston, hence the antenna, is frozen in its position by the lock.

When the servomotor moves the servovalve from its neutral position, one of the cylinder chambers will be connected to the high-pressure line. The direction in which the servovalve is moved by the motor determines which chamber is connected to the high-pressure line. Movement of the valve connects the opposite chamber to the sump tank to allow the oil in the chamber to drain off. The high-pressure oil forces the piston in the cylinder to move. The speed at which the piston will move is determined by the rate of delivery of the oil to the chamber. This is determined by the amount the servovalve is moved from its neutral position. The total movement of the piston (antenna) is determined by the volume of oil in the chamber. This, in turn, is determined by how far the servovalve is moved from its neutral position, and how long it remains off its neutral position.

Response from the antenna is used to bring both the electrical and hydraulic systems to their null positions. This makes sense, since both systems must stop driving when the antenna is at a desired position. If the response voltage from the antenna is equal and opposite to the input error signal voltage, the electrical signal error is zero. The output of the amplifier to the



12.289

Figure 3-10.—Simplified block diagram of an electrohydraulic servo.

servomotor is zero, and there will be no torque on the motor. The hydraulic system is at null when the servovalve is in its neutral position. Mechanical response feeds through the differential linkage to zero the servovalve as the antenna moves. Thus, the input to the servovalve is proportional to the difference between the movement of the servomotor and the movement of the antenna.

To this point, we have not said much concerning servoamplifiers. Obviously the primary function of the amplifier is to increase the strength of the error signal. But, an amplifier has many features which can be used to improve the servo's operation. Many types of amplifiers are used in servos. Therefore, it is not practical to discuss individual amplifiers at this time. We will discuss some of the advantages of having an amplifier in a servo.

An amplifier can increase the signal power to a practical level. The amplifier may be made sensitive to signals with a certain frequency, amplitude, type of voltage, and phase or polarity. The amplifier isolates the signal source from the load, which means that the error signal feeds into the fairly constant impedance of the amplifier's input circuit and not into the variable impedance of the load. At the same time, however, the amplifier's gain can be varied by feedback signals to automatically adjust the amplifier's output to compensate for the condition of the load.

SIGNAL TYPES

A servo's output is an accurate duplication of the input order signal with an increase in power. The order signal represents a desired action, and therefore determines how the servo will respond. The order signal can be a position, a velocity, or an acceleration. Let's consider the three types of order signals.

A position order signal will cause a displacement from a reference point in the servo's output. If we time this displacement, we can obtain a velocity. Velocity is a timed displacement; that is, the rate of change from one position to another. A change in velocity is an acceleration and therefore can be either an increase or decrease in speed or a change in direction of motion.

Order signals must often be converted from one type to another. For example, the fire control radar will measure the displacement of a target from the line of sight. From this displacement a velocity is derived to change the rate of motion of the director to keep it on target. On the other hand, we may have a computed rate of motion and require the displacement which will occur during a given time. We can change the signal because displacement, velocity, and accelerations are functions of each other and each is a derivative of the others. (A derivative is a quantity which is obtained from another quantity.) If we know that a displacement occurred in a measured interval of time, we can derive the rate of motion. And it follows that if we know the rate of motion, we can derive the displacement which will occur during an interval of time.

POSITION SERVOS

The position servo is one whose end function is to control the position of the load it is driving. This type of servo is used to position many devices within the fire control system. Directors, radar antennas, computing elements, and servovalves are some examples.

The electric servo in figure 3-7 and the electromechanical servo in figure 3-9 are examples of position servos.

The input order signal represents a desired position, and the servo is designed to move the load to this ordered position.

The CT error detector in figure 3-9 compares two positions to obtain an error signal equal to displacement. As pointed out in the previous chapter, synchros are basically position-sensing devices. Resolvers and balanced bridge circuits can also detect displacement and are sometimes used in position servos.

VELOCITY SERVOS

The velocity servo is one whose end function is to control the velocity of the load it is driving. In other words, the velocity of the output is of primary concern with this type of servo. Position is of secondary concern. Hence, a velocity servo's primary function is opposite that of a position servo.

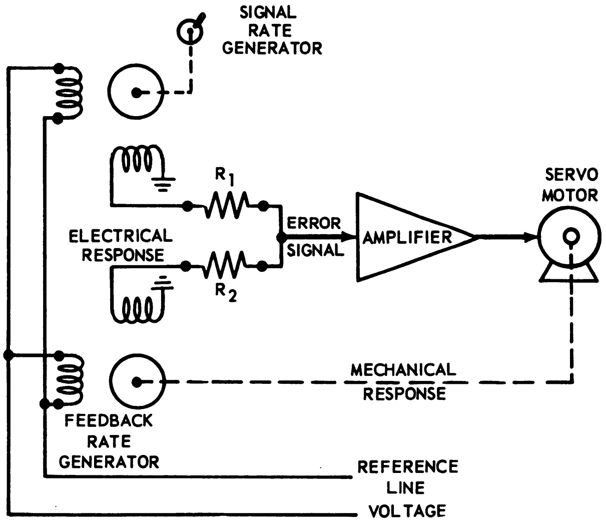
The basic elements of the two types are the same. Each has, at the very least, an error detector, an amplifier, and an error reducer. In position servos, the error signal represents a displacement and is eliminated by reducing the displacement. In velocity servos, the error signal voltage is proportional to a velocity, and is eliminated by a response voltage proportional to the output velocity.

A velocity servo is shown in figure 3-11. The only real difference between this and position servos previously studied is in the rate generators which develop voltages proportional to the velocity of their rotors.

Rate generators, also called tachometer generators, or tachs for short, were covered in detail in chapter 2. If you will turn back to figure 2-27, and the accompanying explanation of the figure, you can refresh your memory on their construction and principles.

SERVO CIRCUITS

In this section of the chapter we will discuss the circuits and the components that make up a servo. Like an iceberg, most of the material necessary to understand servos is below the surface in the basic theory. Again, it is assumed



12.287

Figure 3-11.—Velocity servo.

that you have studied either the *NEETS* module or *Synchro, Servo, and Gyro Fundamentals* (NAVPERS 10105) or some other source material.

We have divided the servo circuits into categories according to the functions that they perform. Here is a brief description of each circuit.

SENSORS

Sensors are devices that measure, convert, or sense the input and output of any servo, and present them in a form suitable for use by the servo. The more common types of these devices convert motion into corresponding electrical energy. These devices are part of the class called transducers.

Servo input (order) information is usually in the form of a voltage or shaft position. The error signal to the servoamplifier is normally an electrical signal. The response (feedback) may be either a voltage or a mechanical quantity. You can see that some energy-converting device is required in almost any servo, as well as a device which measures the position of the input and the output. Potentiometers, synchros, resolvers, and E-transformers are used as sensors.

SYNCHRONIZING CIRCUITS

Synchronizing circuits (also called switching networks) are used to control the input to the servoamplifier from a dual-speed or greater synchro transmission system. The use of a dual-speed synchro transmission system increases the accuracy of the servo. But, a dual speed synchro system introduces a problem—how can a servoamplifier tell when it is, or should be, receiving a fine or a coarse error signal?

A typical dual-speed synchro control system, such as for transmission of bearing angle, has a coarse CT (control transformer), at 1 speed and a fine CT at 36 speed. In this system, response (feedback) from the servo to the fine CT is driven at 36 speed, and each rotation of the shaft represents 10°. Therefore, if the error is large, the servo could synchronize at a false point. To prevent this, control of the servo must be shifted to the coarse CT when the servo is more than two or three degrees out of synchronization.

A synchronizing circuit is included in the servo to sense how far the load is from the ordered position and then to switch the appropriate signal (fine or coarse) into control. The signal selected by the circuit is the input to the amplifier. The selection is based on the size of the error signals the circuit receives. The coarse signal is the predominant factor in the selection, since it is a measure of the servo's output position throughout its limit of motion. The coarse signal drives the system into approximate synchronization, then the fine signal is shifted into control. The servo is normally controlled by the fine CT, the coarse CT has control only when the servo is far out of synchronism.

Common synchronizing circuits employ relays and semiconductor or zener diodes.

A typical synchronizing circuit is shown in figure 3-12. The inputs are the coarse and fine signals from the rotors of the CTs in a two-speed synchro system. The output, the coarse and fine signals combined in the summing network, is applied to the amplifier.

An important thing to remember about this circuit is the amount of voltage that is necessary to forward bias the semiconductor diodes. Let's assume that it takes 1.5 volts to cause a diode to conduct.

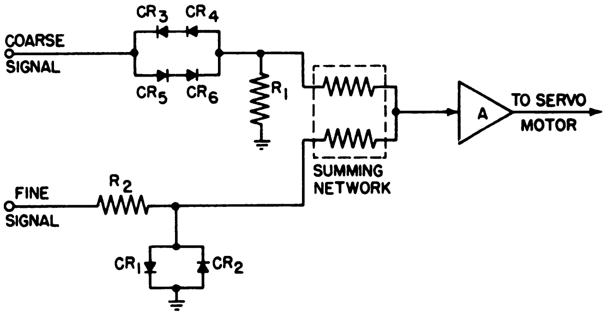


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Figure 3-12.—Semiconductor diode synchronizing network.

Look at diodes CR3, 4, 5, and 6. They are in series with the coarse signal and the amplifier. Since there are two diodes connected together, CR3 and 4, or CR5 and 6, it will take at least 3 volts to pass current through them, and develop a voltage across R1. In other words, any coarse signal voltage that is 3 volts or larger is allowed to be felt at the amplifier. Any coarse signal voltage less than 3 volts will be blocked by diodes CR3, 4, 5, and 6.

Next, look at diodes CR1 and 2. They are in parallel with both the fine signal and the amplifier. In this case, any voltage that is greater than 1.5 volts will be shunted to ground by the diodes. Any voltage less than 1.5 volts will be blocked from ground by the diodes, and felt at the amplifier.

At this time, you should realize that any voltage greater than 3 volts will reach the amplifier from the coarse CT, and any voltage less than 1.5 volts will reach the amplifier from the fine CT. This description of a typical synchronizing circuit agrees with our earlier description. Both fine and coarse synchros are capable of producing large signal voltages, depending on how far they are from synchronization. However, only the large signal from the coarse CT will be allowed to reach the amplifier, and when both synchros are almost at their null, only the small signal voltage from the fine CT will be allowed to reach the amplifier.

If this topic seems familiar to you, it is because we discussed switching circuits in chapter 2. (Refer to figure 2-9 and the accompanying statements.)

MODULATORS

Some servos are designed to have a d.c. error voltage and an a.c. amplifier or motor. Consequently, the d.c. error voltage must be converted to an a.c. voltage that contains the same data (the direction and magnitude of the error) before it can be used by the amplifier. The circuit that converts the error signal from a d.c. to an a.c. voltage is called a modulator. Modulation is the process by which the amplitude, frequency, or phase of a carrier wave is varied with time in accordance with the waveform of a superimposed intelligence. Modulation and demodulation are covered in a *NEETS* module.

In the modulator circuit, the carrier wave is the servo's a.c. reference voltage. The superimposed intelligence is in the d.c. error signal. The polarity of the d.c. error signal indicates the direction of the error, and its magnitude is proportional to the amount of error. The phase between the a.c. error signal and the a.c. reference voltage is controlled by the polarity of the original d.c. error signal. Therefore, each characteristic of the original d.c. error signal has been translated into the new a.c. error signal. The new a.c. is the equivalent of the old d.c.

The modulator circuits use elements that act as synchronous switches. Examples of these elements are: transistors, crystal or metallic rectifiers, diodes, triodes, and mechanical contactors. The elements have a nonlinear, front-to-back resistance ratio, so that current will flow through the "switch" in only one direction. The switches are operated at the carrier frequency, which is usually 60 or 400 hertz. The resulting pulsating voltage is proportional to the d.c. error voltage. The phase of the pulsation voltage is determined by the polarity of the d.c. error signal.

An example of the modulator is shown in figure 3-13. It consists of a diode bridge and transformer network. The a.c. reference voltage is applied to transformer T1. The d.c. input

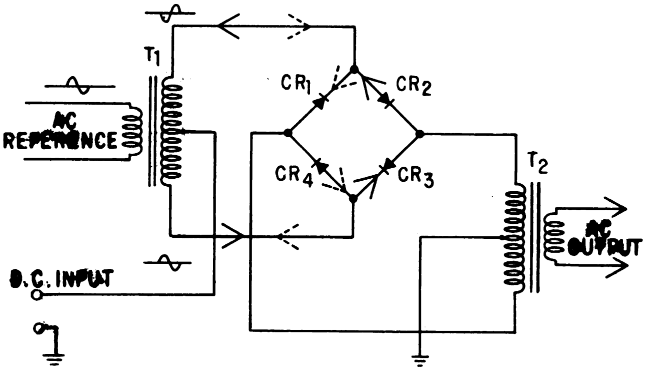

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Figure 3-13.—Crystal-diode modulator.

(error) signal is applied to the center tap of the secondary of transformer T1.

Now, let's see how it works. During the negative half cycle of the reference voltage (there is a 180° phase shift in T1) diodes CR2 and CR3 conduct. Conversely, diodes CR1 and CR4 conduct on the positive half cycle of the reference voltage. Electron flow during the positive and negative cycles is represented by dotted arrows and solid arrows, respectively.

If a positive d.c. input voltage is applied during the negative-going cycle of the a.c. reference voltage, electrons will flow from ground, through the upper half of the primary winding of transformer T2, through diode CR2, and through the upper half of the secondary winding of transformer T1 to the d.c. source. Current flow through the bottom of T2, CR4, and T1 secondary is opposed by the opposite polarity from the bottom of T1 to CR4. This polarity in effect reverse biases CR4 and prevents conduction through the lower half of T2. On the positive-going cycle of the a.c. reference voltage, electrons will flow from ground, through the lower half of the primary of transformer T2, through diode CR4, and through transformer T1 to the d.c. signal source.

If a negative d.c. input (error) signal is applied, electron flow through the circuit is reversed. That is, electrons flow from the d.c. signal source, down through the lower half of T1 secondary, through CR3, through the upper half of T2, to ground.

Note that the direction of current through T2 primary governs the phase of the a.c. output voltage and that this current was reversed by the polarity of the d.c. input signal reversing.

Since, in all cases, electrons are caused to flow through the primary of transformer T1 at the frequency of the reference voltage, the a.c. output will be at the same frequency.

The effect of all of this is that the phase of the a.c. output signal is determined at any given instant by both the polarity of the d.c. input signal and the phase of the a.c. reference voltage. Ultimately, then, this phase determines the direction of rotation of the a.c. servomotor.

DEMODULATORS

Some fire control servos use d.c. servomotors to drive the load. A typical example is an amplidyne power drive. The input signal to an amplidyne servo is usually an a.c. synchro voltage. This requires that the a.c. order signal be converted to a d.c. signal. To accomplish this a demodulator circuit is used. Demodulation is the process of extracting the signal intelligence from a modulated carrier wave. In the amplidyne-type servo, the modulated carrier wave is the a.c. signal from CTs. The magnitude of the a.c. signal is proportional to the size of the error and the phase of the signal indicates the direction of the error. This, then, is the intelligence we must extract.

To derive a d.c. signal having the same intelligence as the a.c. signal, we must be able to detect both the phase and the magnitude of the a.c. signal. The polarity of the d.c. signal is determined by the phase of the a.c. signal compared to a reference voltage. The reference voltage must be from the same source as the synchro's supply, which is the voltage we modulated in the first place. The magnitude of the d.c. signal is directly proportional to that of the a.c. signal.

Demodulators are often referred to as phase-sensitive rectifiers or detectors, phase-discrimination converters, or simply as discriminators and detectors. These are high-sounding names for a circuit with which you are fairly familiar. If you understand the principles of modulators just presented, demodulators will be easy for you.

A typical demodulator is shown in figure 3-14. An a.c. voltage serves as the reference voltage for the demodulator. This voltage must come from the same source that is supplying the a.c. excitation voltage to the error detector of the servo. This permits a phase comparison between the input (error) signal and the reference voltage. The plates of the two diodes are supplied with this reference voltage in such a manner that the two plates are in phase.

Assume that there is no input signal from T2 to the plates of the diodes, and the reference

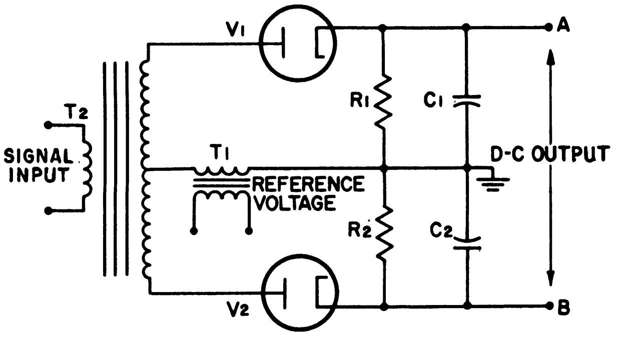

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Figure 3-14.—Diode vacuum-tube demodulator.

voltage is on a positive half cycle. The two diodes conduct equally. The voltages produced across R1 and R2 are equal, making the cathodes of V1 and V2 (and points A and B) at equal potentials with respect to ground. With the two output terminals at the same potential, the output voltage remains at zero volts as long as no error signal is applied.

If an input signal is applied to T2, making the plate of V1 positive at the same time the reference voltage on the plates of V1 and V2 is on its positive half cycle, V1 conduction will be increased and V2 conduction decreased over the no-signal condition. This causes an increase in the voltage drop across R1 above that of R2. The difference voltage now appears between A and B. Because the voltages applied to the plates are alternating, the R1 and R2 voltages continuously change—in effect producing an a.c. between A and B. However, R1-C1 and R2-C2 have long time constants relative to the input frequency, and therefore filter most of the ripple, giving a d.c. output.

If the error signal applied to T2 is changed by 180°, V2 would now increase its conduction, while the conduction of V1 would be reduced. This would result in an output voltage of reversed polarity. The a.c. signal input has been changed to a d.c. signal output that varies in amplitude and polarity.

Variations of the diode demodulator may be encountered; however, they all depend on the same basic principles of operation.

SERVOAMPLIFIERS

Servoamplifiers have several inherent characteristics:

1. Flat amplitude response or gain over the broad band of frequencies of interest

2. Small and fixed phase shift of the output with respect to the input

3. Low output impedance and low nonlinearity

4. Low noise level

It is not practical to discuss individual amplifiers in this text. We have selected a representative transistor amplifier to explain the various functions it performs in a servo. This discussion will help you to understand the amplifiers in your equipment. We will not discuss the theory of the circuits in the amplifier, except the circuits that are unique to servos. The basic theory is covered in the *NEETS* module on amplifiers.

PREAMPLIFIERS

Many servoamplifiers in fire control equipment are of a standard, modular design, each identical with the others. In order to make such a design even more useful, separate, modular, plug-in preamplifiers are available to boost weak input signals to the amplifier. In other applications, preamplifiers are built into the amplifier itself. In either case, the preamplifier is a separate stage used to bring the input signal characteristics within the requirements of the amplifier.

TRANSISTOR POWER AMPLIFIER

Figure 3-15 shows a two-stage transistor amplifier of the plug-in module type. The driver stage increases the error signal voltage to a usable level. The output stage provides the power (current) amplification that is necessary to drive the error reducer.

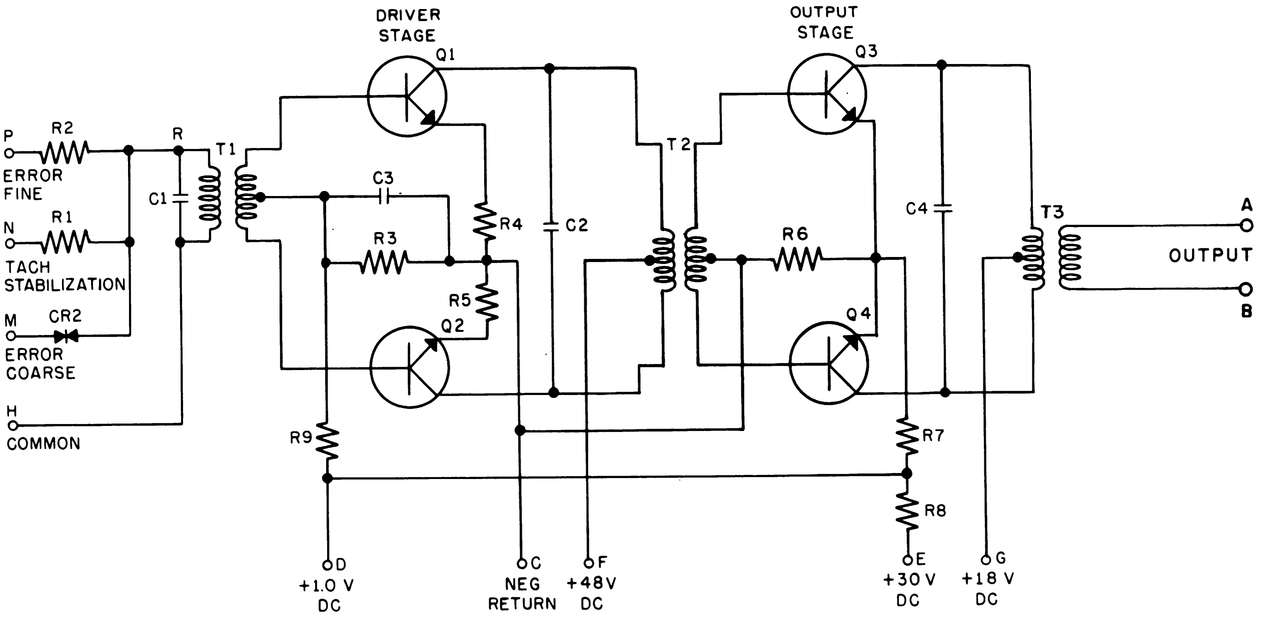

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Figure 3-15.—Transistor power amplifier.

The inputs to the amplifier (pins P and M) are a.c. error signals from either the fine or coarse CT in a two-speed synchro control system. Another a.c. input from a stabilization tach is applied to pin N. The stabilization tach is connected directly to the servo's load and senses its movement (speed and direction). Stabilization allows the servosystem to function more smoothly, with less overshoot and tendency to oscillate. This will be covered in more detail later in the chapter. Pin H is a common return to the amplifier for the CTs and the tach.

The output at pins A and B is also a.c. This is sent to an a.c. split-phase servomotor (error reducer) which drives the load and stabilization tach.

The remaining pins to the amplifier provide power supply and biasing voltages.

The input error signal on pins P and M are from the two-speed synchro control system. Zener diode CR2 is part of a synchronizing circuit, as in figure 3-12, and functions as two diodes connected back-to-back. The fine error signal on pin P is normally in control. If the coarse error signal becomes sufficiently large, it will break down the zener diodes and assume control as previously explained.

The stabilization tach input voltage on pin N is present whenever the load is moving.

The sum of the voltages on pins P, M, and N is applied to the input transformer T1. T1 couples the input and provides two a.c. error signals, 180° out of phase, to the driver stage. The driver stage provides voltage amplification for the two signals. Transformer T2 couples the amplified error signals to the second (output) stage. The two 180° out-of-phase error signals now drive the output stage, which is a typical push-pull power amplifier. The amplified error signal is taken from the secondary of transformer T3 to drive the load and stabilization tach.

The d.c. voltages to the transisitor's collectors are unfiltered and contain a ripple that is in phase with the reference voltage of the synchro system. Therefore, the error signal is either in phase or 180° out of phase with the a.c. component in the collector voltages.

COMPARISON OF AC AND DC SERVOS

Generally speaking, a.c. and d.c. servos are similar. They both meet the basic requirements of a fire control servo and have essentially the same components. The type of servo used is determined by the requirements of the load. Heavy loads with a wide speed range, such as directors and radar antennas, are controlled primarily by d.c. servos. Light loads with a fairly constant speed requirement are normally controlled by a.c. servos.

AC SERVOS

Large a.c. motors are too inefficient for servo use. To obtain the desired torque-speed output curve, the motor becomes too large, draws excessive power, and is difficult to cool. Hence, a.c. servos in fire control equipment are used primarily to control light loads which require low power. Most of the a.c. servomotors are of the two-phase or split-phase induction type. Fundamentally, these motors are constant-speed devices, although their speed can be varied within small limits by varying the amplitude of the voltage to one of the motor's stator windings.

The voltages to the stator windings of a two-phase motor should be exactly 90 electrical degrees apart. The 90° phase relationship can be established by using a capacitor to shift the phase of the voltage to either of the stator windings. Any phase shift that changes the 90° relationship will reduce the motor's efficiency. The direction of rotation of the motor can be changed by reversing the phase relationship between the stator windings.

DC SERVOS

The control characteristics of d.c. motors are superior to those of a.c. motors. The d.c. motor can control heavy loads at variable speeds. Most of the d.c. motors found in fire control equipment are either the permanent magnet type which are used for light loads, or the shunt-field type which are used for heavy loads. The characteristics of these motors are covered in *NEETS* module on motors and generators. When they are used in servos, the strength of the motor's field which is supplied by the magnet or the shunt field is held constant. The direction and the speed of the motor's rotation is determined by the armature current, which is supplied by the servoamplifier. An increase in armature current increases the motor's speed. A reversal of the motor's armature current changes the motor's direction of rotation.

One disadvantage of d.c. servos is that d.c. servoamplifiers tend to drift. Drift is the low frequency variation of the output voltage with no change of the input. Drift is usually caused by changes in power supply voltages or by the change of component values caused by temperature variations, aging effects, and humidity. Drift in d.c. servoamplifiers can be overcome by circuit design. Frequently, however, an a.c. amplifier is used and the output is demodulated. As a result, in some servos you may find modulation and demodulation stages as previously discussed.

OPERATIONAL ACCURACY

A servo should drive rapidly to the ordered position of a fixed input order signal. It should stop at the ordered position with a minimum of motion (oscillations) in the shortest time possible. Once at the ordered position, the servo should hold that position rigidly.

When the input order signal is continuously changing, the servo should drive to the ordered position in the same manner as with a fixed signal, and then drive at the same rate as the changing input order signal.

OPERATIONAL ACCURACY

In a position servo, the rate of movement is established by the rate of displacement. Hence there is a definite lag between the order-signal position and the output position.

The accuracy of a servo is determined by its ability to measure and produce an error signal and to amplify the error signal to a level which will move the load to eliminate the error. Hence, the overall accuracy of a servo is determined by the accuracy of its components and their input data.

The error detector receives and compares the ordered position and the actual position of the servo's output. Any error in the input data will naturally reduce the accuracy of the error detector's output. The accuracy of the error dectector is determined by the amount of difference between its inputs (and on signal and feedback signal) that is necessary to produce a usable error signal.

The gain of the servoamplifier determines how large the error signal must be before the amplifier output is sufficient to drive the error reducer. The higher the gain, the more sensitive the amplifier and the more accurate the servo. The efficiency of the error reducer determines how large the control current must be before it will drive.

The accuracy of the data, error detector, servoamplifier, and the error reducer determines the static error or dead space of the servo. The static error is the angular displacement between the input and output of the servo under static conditions (synchronized to a fixed order signal).

As you can see, operational accuracy is basically a function of design over which you as a technician have little or no control. However, maintaining the original accuracy is in your ball park. The manner in which you adjust and maintain the servos in your system will determine the actual accuracy at any given time.

GAIN, PHASE, AND BALANCE ADJUSTMENTS

In many servosystems you are able to vary the gain of the amplifier by an adjustment. The gain adjustment governs the amplitude or amount of the error signal voltage applied to the amplifier or one of its stages. Normally, the highest gain possible, with the servosystem possessing a satisfactory degree of stability (no jitters or oscillations), is the most desirable.

In a.c. servosystems, another adjustment which can control the sensitivity of the system is the phase adjustment. The phase adjustment is used to shift the phase relationship between the error signal voltage and a reference voltage. In a vacuum-tube amplifier with phase-shift control, the grid signal is shifted in phase with reference to the plate voltage of a thyratron tube. The thyratron tube's firing point is delayed or advanced depending upon the phase shift or grid signal. The phase shift can vary the firing time of the tube over the plate's entire positive alternation.

In a transistor amplifier, the phase-shift adjustment is accomplished by using an SCR (silicon-controlled rectifier). An SCR is the equivalent of a thyratron tube in a vacuum-tube amplifier.

A phase control is included in some servosystems using a.c. motors. The two windings of the a.c. servomotor should be energized by a.c. voltages that are 90° apart. This phase adjustment is included in the system to compensate for any phase shift in the amplifier circuit. The adjustment may be located in the amplifier, or, in the case of a split-phase motor, it may be in the uncontrolled winding.

A servosystem using push-pull amplifier must be balanced so that when there is no signal input to the amplifier, its output will be zero, and the servomotor will stand still with no creep. The push-pull amplifier must ensure equal torque in both directions of the servomotor.

Gain, phase, and balance adjustments are often present in one amplifier. These adjustments tend to interact, so that when one of them is changed it may affect the others. Therefore, after you make any one adjustment, it is a good practice to check the others.

RESPONSE TIME

Fire control requires a servosystem to operate smoothly, rapidly, and with as few errors as possible. To obtain these operational characteristics, one quality is counterbalanced against the other. To increase the rapidity of response of the system to a signal, the gain is increased. This also tends to reduce error in the system. But, a high gain or "tight" servo has a tendency to overshoot or oscillate, or, in other words, to be unstable. Response or synchronization time is the time the servo requires to settle down and follow an order signal.

"HUNTING"

A servo will drive its load to the correspondence position. The servo's error signal and output torque are zero at correspondence; but, because of the load's inertia it will continue to move. As the correspondence point is passed, the error signal tends to reverse the direction of movement. However, a short time is needed to stop the load; and, during this time, the load continues to move away from correspondence. When it does stop, the error signal will drive the load back towards correspondence. At correspondence the load has again acquired sufficient inertia to drive on past. The result is a series of overtravels of the correspondence point (fig. 3-16), really oscillations of a low frequency.

This condition is called "hunting," and is a characteristic which must be corrected in all servos. Obviously, hunting reduces the smoothness of the servo's followup action and increases its synchronization time. To overcome hunting, the servo must anticipate the load's inertia and its position with respect to the correspondence point.

Servos may also tend to oscillate at higher frequencies. For example, a servo with a high-gain amplifier has a tendency to oscillate at a high frequency with a low amplitude. The high-frequency oscillations are started by some type of disturbance or variation such as random noise in the electrical section of the servo or lost motion in the mechanical section. Once the oscillations are started, the high gain of the amplifier tends to assist them while the inertia of the load continues to reintroduce the error caused by the oscillation.

DAMPING

To obtain smoothness of operation, the system's gain is damped. Damping can be obtained by either introducing a voltage in opposition to the error signal voltage or placing a physical restraint on the servo output. The function of damping is to reduce the amplitude and duration of the oscillations that may exist in the system. Every system has one or more natural oscillating frequencies which depend on the weight of the load, designed speed, and other characteristics.

The degree of damping is determined by the required characteristics of the servosystem. If the system is OVERDAMPED, it will not oscillate about the correspondence point. However, because of the large amount of restraint placed on the servo, it will have a comparatively large dead-space or steady-state error. The overdamped servo will also take an excessively long time to synchronize (fig. 3-17).

On the other hand, the UNDERDAMPED servosystem will have instant response to an error signal. But, it will have erratic operation because of the low amount of restraining force placed on the servo, and will oscillate about the point of synchronism. Somewhere between these two extremes, we can obtain adequate accuracy and smoothness plus a moderately short synchronizing time.

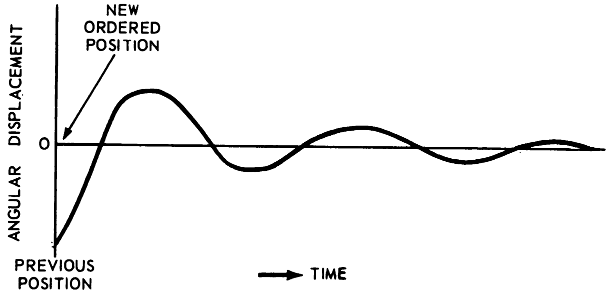

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Figure 3-16.—Overtravel about the correspondence point.

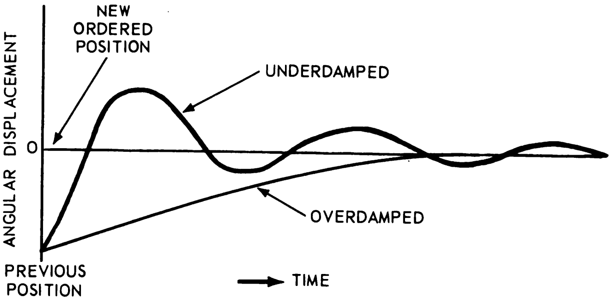

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Figure 3-17.—Degree of damping.

Viscous Damping

The simplest form of damping is viscous damping (mechanical friction). This is the application of friction to the output shaft or load that is proportional to the output velocity. The amount of friction applied to the system is critical, and will materially affect the results of the system. The application of friction absorbs power from the motor, and this power is dissipated in the form of heat.

A pure viscous damper would absorb an excessive amount of power from the system. However, a system having some of the characteristics of a viscous damper, but with somewhat less power loss, is used in actual practice. The first damper of this type to be discussed utilizes a friction clutch to couple a weighted flywheel to the output drive shaft. A flywheel applies the property of inertia.

FRICTION CLUTCH.—As the servomotor rotates, the clutch will couple a definite amount of this motion to the flywheel. The flywheel will gradually overcome its inertia and gain speed until it approaches the velocity of the motor. The flywheel, in turning, absorbs energy (power) from the servomotor. The amount of energy stored in the flywheel is determined by its velocity. Because of inertia, the flywheel will resist any attempt to change its velocity.

As the point of correspondence is neared and the error signal is reduced, the motor starts to slow down. The flywheel immediately releases some of its energy into the output shaft in an attempt to continue at the same speed. Thus, the flywheel will cause a large first overtravel. The servosystem, to correct for this overtravel, reverses the direction of the motor. Once again the flywheel resists the motor movement and absorbs energy from the system. This drastically reduces the second overtravel and all subsequent overtravels of the motor. This effect dampens the oscillations about the point of correspondence and reduces the servosystem's synchronizing time.

The motor rotation is transmitted to the flywheel through the friction clutch. The inertia of the flywheel is an additional load on the motor. The friction clutch will slip with any rapid change of direction or speed. This slipping effectively disconnects the flywheel instantaneously, and thus governs the amount of power the flywheel will draw from the motor.

MAGNETIC CLUTCH.—Another type of viscous damper is the MAGNETIC or EDDY-CURRENT damper. The magnetic-clutch damper is functionally similar to the friction-clutch damper. The principal difference between the two is in the method of coupling the flywheel (inertia weight) to the servomotor output shaft. In the magnetic damper, the shaft and flywheel are coupled by a magnetic field, rather than a frictional contact. The coupling is made by the interaction of a magnetic field generated by a permanent magnet which rotates with the rotor of the servomotor and the induced eddy current in the flywheel.

The effect of viscous damping is shown in figure 3-18. The solid line shows the action of the load without damping. The time required to reach a steady-state condition should be noted. This time is greatly reduced with damping, although the initial overshoot is increased. Viscous dampers effectively reduce transient oscillations, but they also produce an undesirable steady-state error (velocity lag or position error). Since the friction damper absorbs power from the system, its use is normally limited to small servomechanisms.

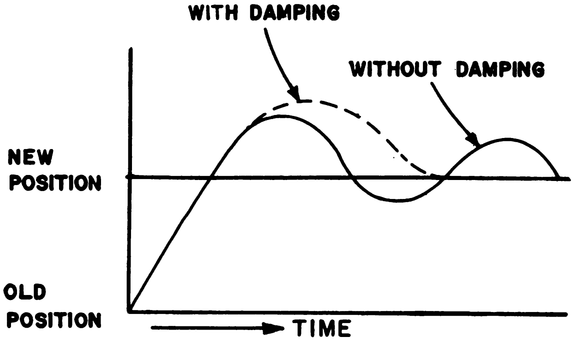

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Figure 3-18.—Effect on friction damper.

Error-Rate Damping

Since no physical device can respond instantaneously to a sudden force, there is a time lag between the order signal input of a servosystem and its output response. To reduce this time lag, amplification is increased. We know that this also increases the tendency of the system toward instability. Viscous dampers act as part of the servo load, so they are not the answers to reducing the response lag. The answer lies in increasing amplification while reducing the tendency toward instability. Error-rate damping does this.

Error-rate damping consists of introducing a voltage that is proportional to the rate of change of the error signal. This voltage is combined with the error signal in the proper ratio to obtain optimum servo operation with negligible overshooting and oscillations.

The advantages of error-rate damping are:

1. Maximum damping occurs when a maximum rate of change of error signal is present. This normally occurs when the servo load reverses direction. Obviously, this is when maximum damping action is required.

2. Since a CHANGE in the signal causes damping, there is a minimum amount of damping when no signal, or a signal of constant strength, is present. This means small, steady-state errors.

ELECTROMECHANICAL ERROR RATE VOLTAGE DEVICE.–Error-rate voltages are generated by either electromechanical devices oı electrical networks in fire control equipment. An electromechanical device widely used to generate an error-rate voltage is the tachometer generator. The tach is mechanically coupled to, and rotates with, the servo's output shaft. Its output voltage is proportional to the output velocity of the servo. Since the voltage output is proportional to load velocity, it is also proportional to the inertia of the load caused by its velocity. Hence, the output voltage can be fed back to the amplifier to indicate the load's velocity, and, therefore, its inertia.

ELECTRICAL ERROR-RATE VOLTAGE NETWORK.–An electrical network used for error-rate damping consists of a combination of resistors and capacitors forming an RC integrating network. From your study of basic electricity, you know that an integrating circuit produces an output voltage that is proportional to the rate of change of the input voltage. In an RC circuit, if the voltage across the capacitor is the output, it is referred to as an INTEGRATOR (fig. 3-19).

Servos used in fire control equipment are required to follow an input signal which is sometimes changing at the constant rate and sometimes at a variable rate. A director's train power drive is an example of a servo whose input signal may be fixed, changing at a constant rate, or at a variable rate. When the director is tracking a target on a steady course and speed, the train rate may be constant. However, if the target changes course or speed, the director train drive may require a sudden acceleration. It can be seen that this servo must adapt itself to a variety of signal types, and respond to them with almost zero error.

Let's use the integrator circuit, or, as it is sometimes called, an integral control, shown in figure 3-19, to explain error-rate damping. The integral control circuit is shown in its simplest form. It is made up of a combination of two resistors and a capacitor. Notice that the network is in series with the error detector and the amplifier. The circuit is designed for d.c. signals. If the error detector puts out an a.c. signal, it must be demodulated before it enters the network. The signal is dropped across R_2 and the R_1, C_1 leg of the network. The R_1, C_1 leg is in parallel with the amplifier's input

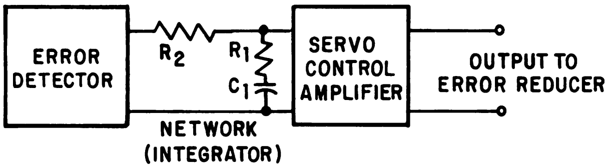

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Figure 3-19.—Integrator used as an integral stabilization network.

circuit. Therefore, only that portion of the signal developed across the R_1, C_1, leg is fed into the amplifier. R_2 is in series with the leg and is larger than R_1. Briefly, here is how the circuit works.

Assume that the error signal is steady or changing slowly. Initially, all of the constant error voltage is divided between R_1 and R_2. But the longer the error voltage is applied, the more C_1 charges up. The increasing voltage drop across C_1 adds to the drop across R_1. Since these two components are in parallel with the amplifier, their combined voltages will appear at the input terminals of the amplifier. In effect, the servo will overcorrect the error signal and the output shaft will catch up with the input signal. As the drive increases its velocity, it reduces the error signal. The capacitor C_1 will start to discharge and oppose the reduction. The damping action of the capacitor's charging and discharging voltages, which oppose the changes in the error signal will assist the servo to settle down quickly at the new velocity.

This discussion of an integral control is by no means complete. There are many types of RC circuits and many different applications of their use for error-rate damping in servos. However, the discussion does cover the fundamental operation of an electrical RC network which can provide error-rate damping.

POSITION SERVOS IN FIRE CONTROL

The fire control problem is a geometric problem dealing with angles, reference planes, lines, and vectors representing motions and forces. Elements used to measure or compute these quantities must be positioned accurately to solve the problem of hitting a target. For example, if we are to compute the wind effect on a projectile, we must establish the wind vectors with respect to the line of fire. The primary concern in the example is the position of the two quantities. Naturally, position servos would be used to control these computing elements. There are many position control servos in fire control equipment. Some examples are:

1. Director or radar antenna power drives in the designation mode of operation. In this mode the director establishes the position of the target.

2. Position control of computing elements, except those which deal with the dynamic generation of the time rate of change of a quantity.

3. Position control of stabilization quantities such as level and cross level.

VELOCITY SERVOS IN FIRE CONTROL

In the velocity servo shown in figure 3-11, when the output voltage of the feedback rate generator is equal and opposite to the signal rate generator's output voltage, the load is moving at the correct velocity. The accuracy of the servo is measured by the difference in velocity between the input shaft and the output shaft. Since, in all servos, an error must exist before a correction can be made, there is a certain amount of lag in the servo's output velocity. The amount of lag is determined by the accuracy of the rate generators, the servo's detecting devices which furnish the servo with its operational data, and the sensitivity of the servo amplifier to an error. We can increase the sensitivity of the servo to reduce the lag by increasing the gain of the amplifier. But, as we have seen, if we oversensitize the servo, it will become unstable. The load will alternate between leading and lagging the correct velocity, and an almost continuous acceleration will occur. Thus, as in position servos, we accept a small error (velocity lag) to obtain smoothness of operation.

In the elementary servo shown in figure 3-11, no means were provided to measure shaft position. But, in most applications, the position of the output is as important as its velocity. Therefore, a position sensing device is normally used as a signal source in velocity servos. We could obtain the same results with a CT by turning its rotor as a function of time; that is, so many degrees per second, as we did with the rate generators. As you rotate the handcrank, there would be a timed velocity. Hence, the accuracy of the servo is measured by how close the servo's output follows a movement from a position already established. This is referred to as the servo's dynamic fidelity.

Stability in velocity servos is obtained by damping in much the same manner as in position servos. However, there is a zero velocity lag when the servo is static and maximum velocity lag when the servo is driving at maximum speed. Hence, velocity lag is a dynamic error proportional to velocity. This error will result in a position error. In a servo where the rate (velocity) is very high, the position error caused by velocity lag is excessive. In such a servo, a derivative (differentiator) circuit could be used to provide an output proportional to changes in its input voltage. Since the input voltage is proportional to velocity the output of the derivative circuit (fig. 3-17) is proportional to a change in velocity or an acceleration. A derivative circuit is a differentiator circuit.

Velocity servos are used in equipment requiring an output velocity corresponding to an input order voltage. Their use in fire control equipment is mainly in the target tracking loop. The director and radar antenna power drives are velocity servos when they are in the automatic tracking mode of operation. Computing elements used to generate target position in some computers are controlled by velocity servos. Many of the gun mount's power drives follow the fire control computer signals as velocity servos.

SUMMARY

Servos consist of devices that work in a system to position or control a load in response to a relatively weak input signal. Servosystems are used throughout every major unit of gun fire control systems.

An operational servo may be electric, electromechanical, or hydraulic. No matter what type or complexity, each servo has an error detector, servoamplifier, and error reducer as major components. Each of these components may take several forms. But, no matter what the specific form, these components always have the same function in the system.

The error detector's output is a signal that represents what the load must do to respond to the order signal. Basically, it is a comparison between where the load is and where it must be driven.

The relatively weak error signal is amplified in the servoamplifier and is used to drive the error reducer.

The error reducer, a servomotor, drives the load in accordance with the order signal. A feedback from it to the error detector continuously reduces the error detector's output until the error is finally nulled. At this point the load has responded to the order, and the movement ceases.

Error reducers may be either a.c. or d.c. Each type has its own characteristics and requires its own specific circuitry. Conversion of a.c. to d.c. and d.c. to a.c. is often required.

Servos may be designed as either position systems or velocity systems, depending on their ultimate function in the fire control system. Position systems were described earlier. The response to an order is a movement to a specific point. In velocity systems, the rate of movement is the important factor.

As an FTG, you need to have a thorough understanding of how servos work in order to accomplish repair, alignment, and installation tasks that will be required of you in all FTG billets.

CHAPTER 4

GYROSCOPES

INTRODUCTION

The purpose of this chapter is to introduce you to gyroscopes in fire control equipment. Because you have studied the basic fundamentals and functions of gyroscopes in *NEETS* or some other course, this chapter will give you only a brief review of the basics of gyroscopes, and a more detailed coverage of their application in gun fire control systems.

WHAT IS A GYROSCOPE

A gyroscope (gyro for short) is essentially a sensing device. It is capable of detecting and measuring motions and forces about an axis or reference plane of interest. Motions and forces are basic quantities in the fire control problem.

Any rapidly spinning object—a top, a wheel, an airplane propeller, or a spinning projectile—is fundamentally a gyro. Strictly speaking, however, a gyro may be defined as a mechanical device containing a spinning mass which is universally mounted: that is, mounted so it can assume any position in space and maintain that position. Figure 4-1 shows a model of a universally mounted gyro. As you can see, a heavy wheel (rotor) is axle mounted so that its spin axis is free to point in any direction. The wheel can spin about axis X, it can turn about axis Y, and finally, turn about axis Z. With this mechanical arrangement, the spinning wheel can assume any position in space. Thus, our model gyro meets the requirements of the definition.

WHY GYROS ARE NEEDED IN FIRE CONTROL SYSTEMS

As you can imagine, it would be very difficult to hit a target if you were on a platform that was rolling and pitching. This is precisely the problem of the gun mounts on Navy ships. It would be much easier to hit a target if the guns were on a stable platform, or at least appeared to be. This is how gyros perform in gun fire control systems.

All fire control systems need gyros for stabilization. (See Fig. 4-2.) Stabilization is the establishment of a stable platform and compensates for the rolling and pitching of the ship. This stable platform, called the horizontal plane, is an unvarying reference from which the fire control problem (covered in chapter 5) is computed.

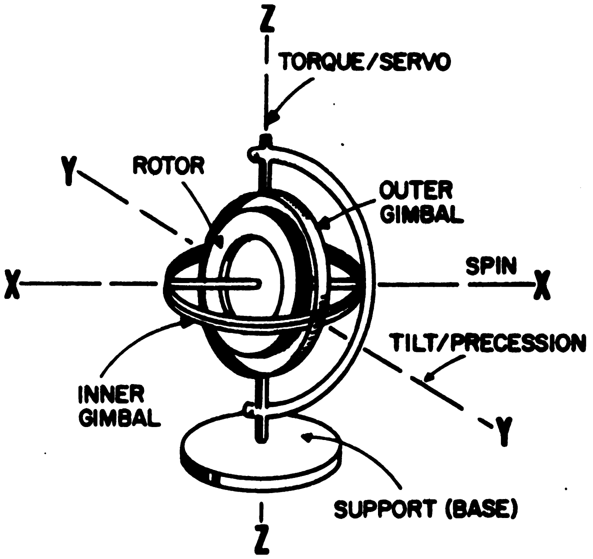

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Figure 4-1.—Basic universally mounted gyro.

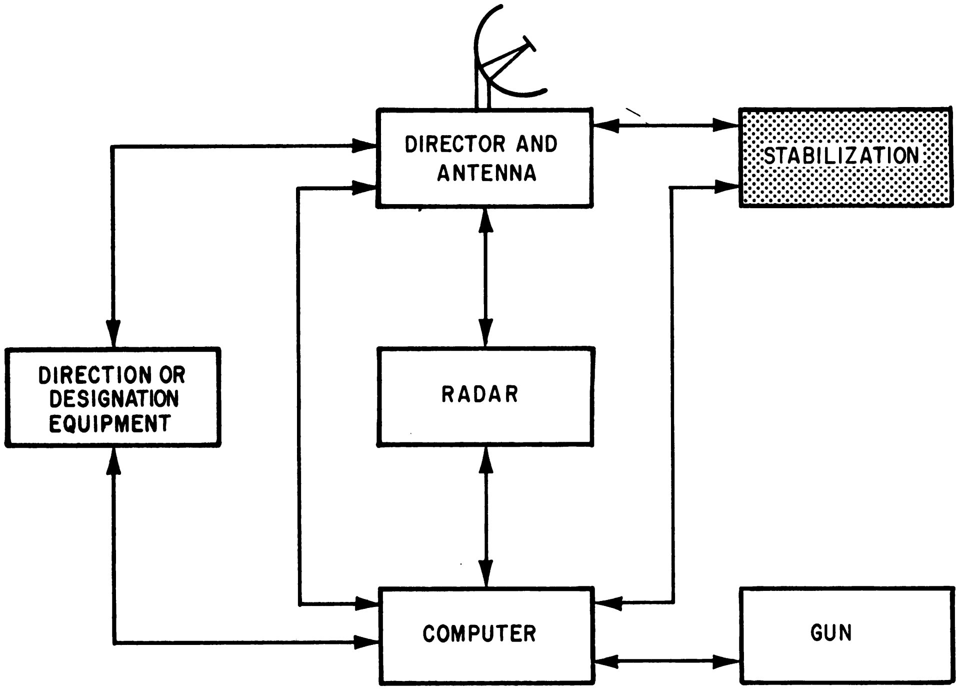

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Figure 4-2.—Gyros are used for stabilization in all fire control systems.

BASIC PROPERTIES OF GYROSCOPES

Gyroscopes have two properties which make them useful in fire control.

1. The axis of rotation (spin axis) of the gyro wheel tends to remain pointed in a fixed direction in space if no force is applied to it.
2. The axis of rotation has a tendency to turn at a right angle to the direction of an applied force.

RIGIDITY

Rigidity is the ability of a gyro's rotor to maintain a fixed position in space. This property offers resistance to any attempt to TILT the rotor from whatever position it has assumed. The rotor can be moved easily as long as the movement is parallel or perpendicular to its spin axis. In other words, if the spin axis of a gyro's rotor is vertical, it can be easily moved up or down, left or right, and fore or aft. However, if we try to tilt, or tip over the rotor, it will offer resistance in an attempt to maintain its axis in a fixed position in space.

PRECESSION

A gyro is a true space device with regard to its ability to maintain its axis in a fixed direction. In order to provide useful information, its spin axis must be related to some reference, usually the Earth's surface. This is done by using the second basic property of a gyro, called precession. Precession may be defined as the resultant movement of a spinning mass when a force is applied that attempts to tilt the spin axis. The precession caused by this force is always about an axis at right angles to the axis about which the force is applied.

In figure 4-3A, to show the effect of precession, imagine pushing down on the gimbal ring at point A at the nearer end of the Z-Z axis.

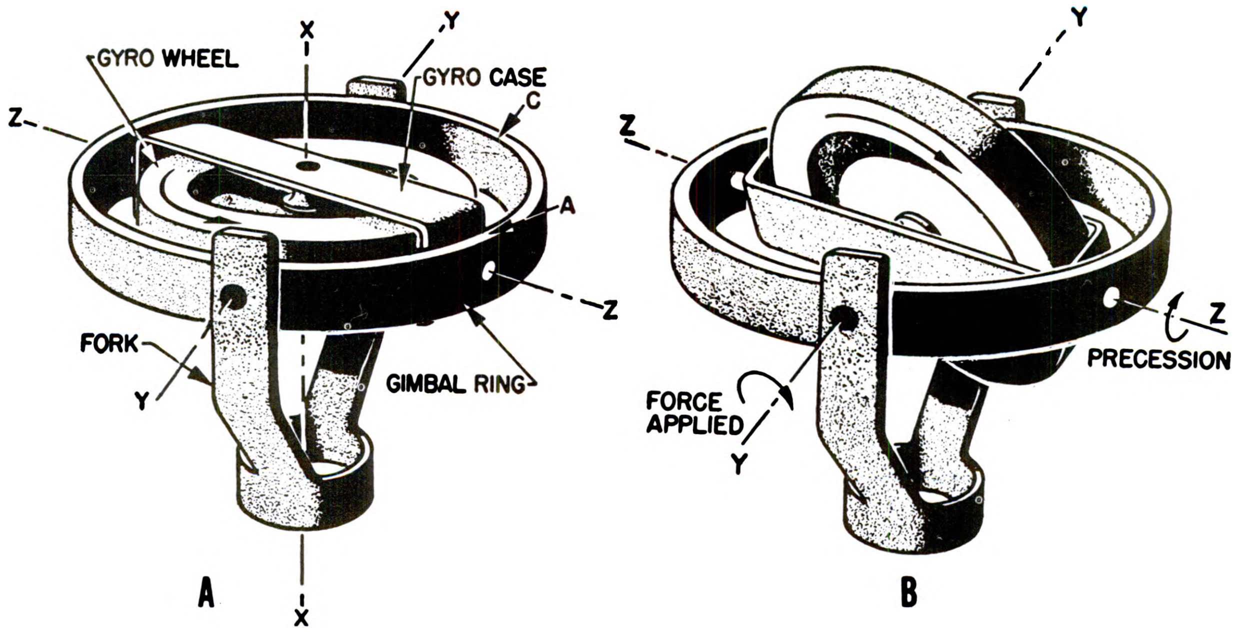

Figure 4-3.—Gyro action.

You might expect the ring to tilt around the Y-Y axis. Instead of rotating about the Y-Y axis, however, the gyro case turns about the Z-Z axis. You can see the effect of precession in figure 4-3B.

Similarly, referring to figure 4-3A, suppose you push sideways on the top of the X-X axis (the spinning axis of the gyro), trying to rotate the wheel around the Z-Z axis. Then, instead of rotating about the Z-Z axis, the gimbal ring will turn around the Y-Y axis.

Here is a rule that applies to all spinning gyros: THE GYRO WILL ALWAYS PRECESS AT RIGHT ANGLES TO THE DIRECTION OF THE APPLIED FORCE.

Look at figure 4-3A again. If you keep pushing down on the gimbal ring at point A, the gyro case will keep turning until the axle of the gyro wheel is horizontal. Then there will be no further precession. At this point, the gyro wheel is spinning in the same direction in which the applied force is pushing.

Here's another rule: A GYRO ALWAYS PRECESSES IN A DIRECTION TENDING TO LINE ITSELF UP SO THAT ITS ROTOR SPINS IN THE SAME DIRECTION THAT THE APPLIED FORCE IS TRYING TO TURN IT. In other words, the spin axis chases the torque axis. When the two come into coincidence, precession no longer takes place. This condition is commonly referred to as "gimbal lock."

Any force that tends to change the plane of rotation causes a gyroscope to precess. Precession continues as long as there is a component of force acting to change the plane of rotation, and precession ceases immediately when the force is removed. It should also be noted that the gyro remains in this precessed condition, thus establishing a new position for the spin axis and reestablishing its rigidity. If the plane through which the force is acting remains unchanged, the gyroscope precesses until the plane of the rotor is the plane of the force. When this position is reached, the force is about the spin axis and can cause no further precession.

GYRO APPLICATIONS

A gyro is capable of measuring the angular displacement of its support mounting from its spin axis or reference plane. Because the spin axis of the gyro is fixed in space, the gyro can provide stabilized reference planes from which the various angles, lines, and motions in the fire control problem can be measured. In figure 4-4, the gyro represents the stabilizing unit of a fire control system. The gyro, because of its rigidity, is unaffected by the ship's roll and pitch. In a manner of speaking, the ship is rolling about the gyro. The gyro measures the angular displacement of the deck plane out of the horizontal plane. Corrective signals that are a measure of the displacement are generated to obtain a stabilized problem.

A gyro can also be used to determine the angular velocity of its support mounting about a reference plane. Since a gyro will precess when acted on by an external force, we can use this property of a gyro to obtain angular velocity. For example, a special type of gyro can be mounted in a director so that the angular motion of the director is a force acting on the gyro. The gyro will precess an amount directly proportional to the angular rate of the director's motion. We will cover this type of gyro, the rate gyro, later in this chapter.

BASIC ELEMENTS OF GYROS

When a gyro is mounted on only one gimbal, it is said to have one degree of freedom. A gyro wheel is mounted in a gimbal and spins in the Y-Y axis (fig. 4-5). When the wheel is spinning, it has rigidity in the Y-Y spin axis and will resist an attempt to change its plane of rotation. The gimbal is supported in the two arms of the gyro case, and can pivot about the X-X output axis. The X-X axis is the only axis in which the gyro can precess, thus classifying this as a single-degree-of-freedom gyro. In all other directions there is a fixed mechanical coupling between the gyro and its mounting. The gyro case can be rotated about the Z-Z axis. The single-degree-of-freedom gyro is sometimes referred to as a restrained gyro.

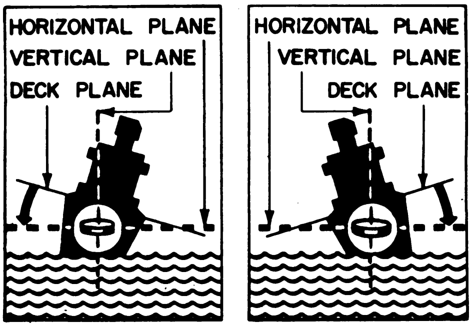

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Figure 4-4.—Stabilization establishes the vertical and horizontal planes.

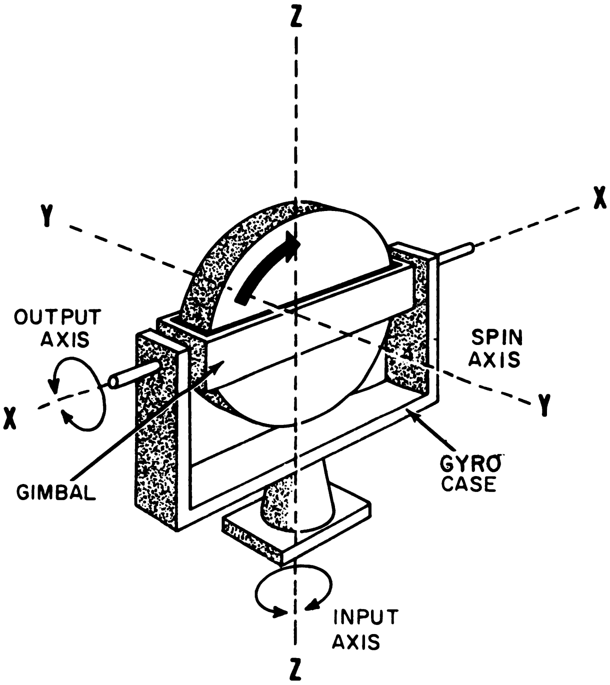

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Figure 4-5.—Single-degree-of-freedom gyro.

A gyro mounted in two gimbals (fig. 4-1) has two degrees of freedom. When two gimbals are employed, it is said to be universally mounted, or a free gyro.

Sometimes you will read in OPs or hear about a three-degree-of-freedom gyro. Do not let this terminology confuse you. It results from counting the spin axis as a degree of freedom.

FORCES THAT AFFECT GYROS

As you know, a free gyro maintains its axis fixed in space. This is true as long as there are no forces that would cause the gyro to drift or precess away from that axis. In order for a gyro to be useful to us, we want to use its spin axis as a reference from which to measure some displacement. A free gyro will always have some forces which affect its ability to maintain a fixed point in space. These forces and how they are compensated for will now be examined.

EARTH'S ROTATION

A free gyro maintains its spin axis fixed in space, and not in relation to the earth's surface. To understand this, imagine yourself in a space ship somewhere out in space and looking at the South Pole of the earth. You could see a sphere rotating clockwise, with the South Pole in the center. Maneuver your ship until it is directly over the South Pole, and then cut in the automatic controls to keep it in this position. The sphere you see would make a complete rotation every 24 hours.

You could keep track of that rotation by driving a big post into the Equator, as shown in figure 4-6A. If this post were upright at 1200, the earth's rotation would carry it around so that it would be horizontal and pointing to the right, or east, at 1800. Likewise, the earth's rotation would carry the post around so that at 2400 it would be upside down. Then, at 0600 the next day, the post would be horizontal and pointing left, or west. Finally, at 1200 the next day, the post would be back in its original position, having been carried with the earth through its complete rotation. Notice that the post has many positions as you observe it–because it is attached to the earth's surface and does not have rigidity in space.

If you put a gyroscope in place of the stake you would see a different action. Imagine a gyroscope mounted at the Equator with its spin axis aligned with the east-west axis of the earth. The gyro is spinning and DOES HAVE RIGIDITY IN SPACE. Look at figure 4-6B. At 1200, the spinning axis is horizontal with respect to the earth's surface. At 1800, the spinning axis is vertical with respect to the earth's surface; but, the gyro is still spinning in the same plane as before, and the black end is pointing away from the earth's surface. At 2400, the spinning axis is again horizontal. At 0600 the next day the spinning axis is again vertical, and the black end points toward the earth. Finally, at 1200 the next day, the gyro is in the same position as when you started. In fact, the gyro wheel spinning on its axis has not changed the direction in space of its plane of spin in being carried through the whole rotation of the earth. This is an example of a gyro being RIGID IN SPACE.

You have just imagined observing the gyro from space. Now, let's come back to earth and stand right next to the gyro. Look at the gyro in figure 4-6C. From your viewpoint on earth, the spinning axis appears to make one complete rotation in one day. Actually, as you know, the gyro is rigid and both you and the earth are rotating.

The effect on a gyro of the earth's rotation is sometimes called APPARENT DRIFT, APPARENT PRECESSION, or APPARENT ROTATION.

MECHANICAL DRIFT

A directional error in a gyro is produced by random inaccuracies caused by mechanical drift and the effect of the earth's rotation (apparent drift).

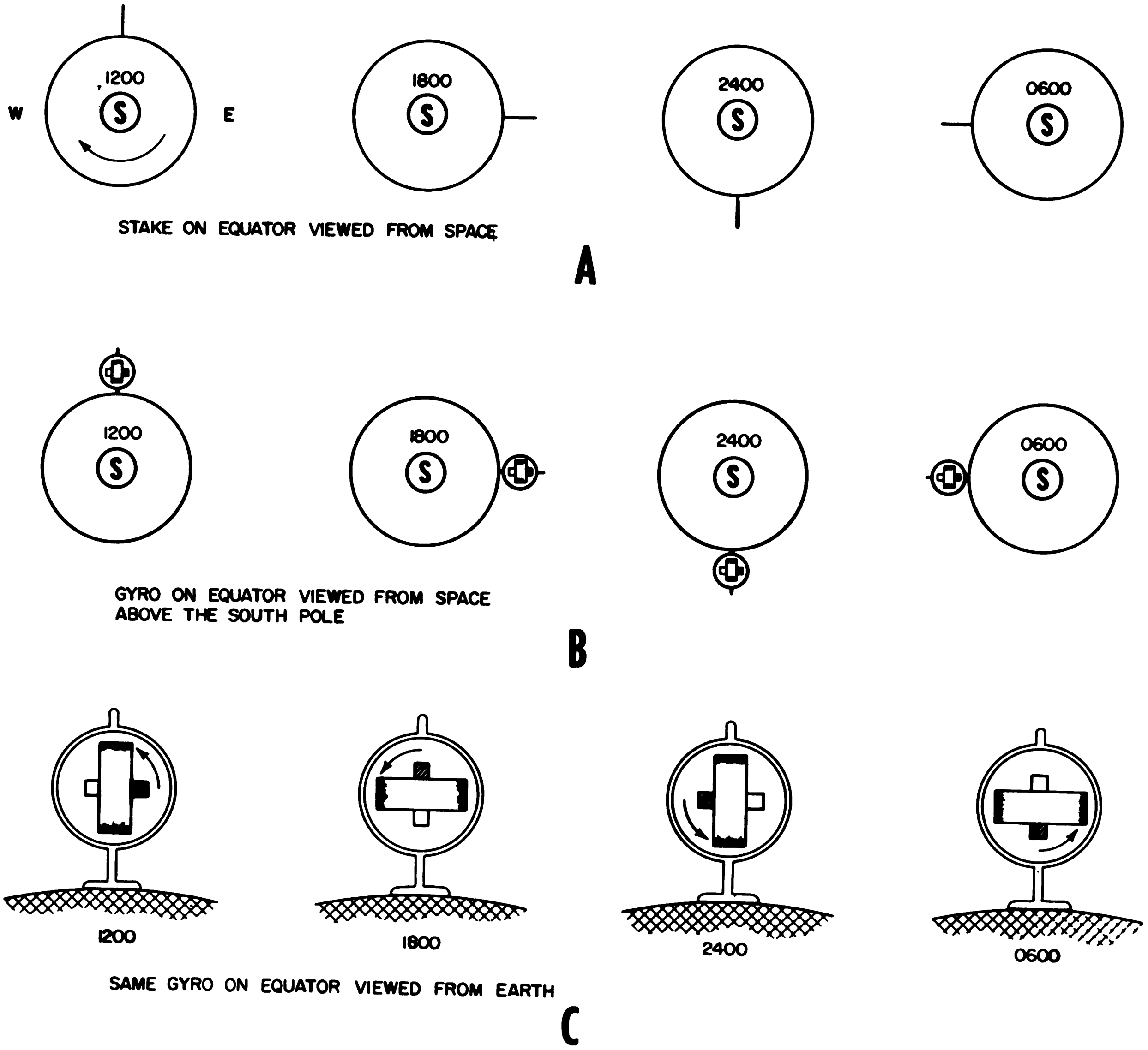
We shall see later on how it is corrected for in the stable element. First, let's consider the causes of mechanical drift.

There are three general sources of mechanical drift:

1. Unbalance. A gyro often becomes dynamically unbalanced when operated at a speed or temperature other than that for which it was designed. The static balance of the gyro is

upset when its center of gravity is not at the intersection of the three major axes. Some unbalance of both types will exist in any gyro, since manufacturing processes cannot produce a perfectly balanced gyro.

2. Bearing friction. Friction in the gimbal bearings results in loss of energy and incorrect gimbal positions. Friction in the rotor bearings causes mechanical drift only if the friction is not symmetrical. An even amount of friction all


1200
W
S
E
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2400
S
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S
STAKE ON EQUATOR VIEWED FROM SPACE
A
1200
S
1800
S
2400
S
0600
S
GYRO ON EQUATOR VIEWED FROM SPACE
ABOVE THE SOUTH POLE
B
1200
1800
2400
0600
SAME GYRO ON EQUATOR VIEWED FROM EARTH
C

A. Post on the Equator viewed from space.
B. Gyro on Equator viewed from space.
C. Gyro on Equator viewed from Earth.

12.144

Figure 4-6.—Fixed direction in space.

around in a rotor bearing results only in a change in the rate of rotation.

3. Inertia of gimbals. Energy is lost whenever a gimbal rotates because of the inertia of the gimbal. The greater the mass of the gimbal, the greater the drift from this source.

The complete elimination of mechanical drift in gyros appears to be an impossibility. However, by proper design it has been kept to a minimum. Any error which still exists can be corrected.

KEEPING THE GYRO HORIZONTAL OR VERTICAL

A free gyro with its spinning axis vertical or horizontal to the Earth's surface is a direction-indicating device. Once set, it continues to point in the vertical or horizontal as long as no disturbing forces cause it to precess from this position. But given time, it will precess, because the disturbing forces caused by apparent and mechanical drift are always present. To find and maintain a vertical, horizontal, or any other position, a gyro-erection system is necessary.

To make a gyroscope into a direction-indicating device which indicates accurately at all times, the following requirement must be met.

1. Torques must be provided of the correct magnitude and direction to precess the gyro in such a manner that the spinning axis is brought to the desired direction after the rotor has been set spinning.
2. Torques must be provided to precess the gyro back to the required position at the proper rate and direction so as to cancel the effects of apparent and mechanical drift.

The torques required to produce the proper precession to convert the gyro into a direction-indicating device are provided by an erecting system. Erection may be accomplished pneumatically, mechanically, or electrically, depending on the type of power available. It usually acts in response to the force of gravity. Specific erection systems are many and varied. We will discuss some of the systems later. When used, erection is a continuous process. Remember, once the gyro has been set spinning in the desired direction, erection is necessary only when the time the gyro is in use is long enough for the earth's rotation and mechanical drift to have effect.

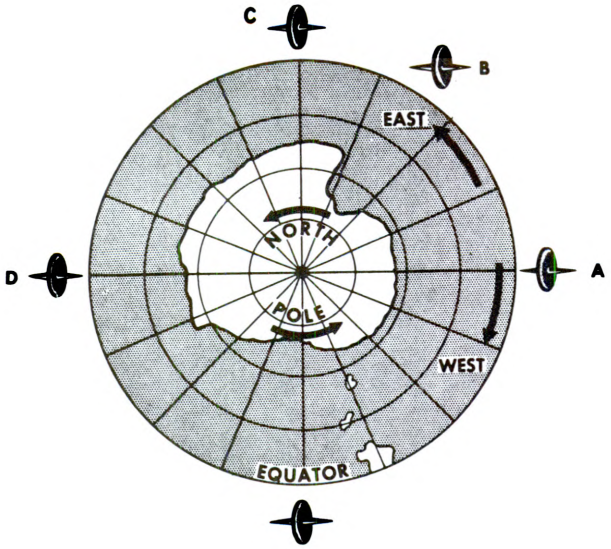
Go back to figure 4-3A, and suppose the base of the fork is fastened to the rolling and pitching deck of a destroyer. A roll of the ship tilts the fork, thus lowering the nearest prong. This SHOULD have no effect on the gyro. The gyro case should rotate on the Z-Z axis, and the gyro should stay vertical. Now, suppose there is a little FRICTION in the Z-Z bearings. This will exert a slight DRAG on the gyro case, tending to ROTATE the gyro about the Z-Z axis, causing the gyro to precess AWAY FROM THE VERTICAL, about the Y-Y axis.

That means you need some corrective force which will bring the gyro back to the vertical when it wanders away. This force is provided by the gyro ERECTING SYSTEM.

LATITUDE CORRECTION

The ROTATION OF THE EARTH has a continuous effect on the gyro. Remember that gyroscopic stability means that a gyro axle tries to maintain a fixed direction IN SPACE. But the Earth, as it rotates toward the east, is rolling under the gyro. Therefore, to an observer standing on the Earth, the gyro appears to keep tipping westward. Apparent rotation was described and effect was observed from a position over the South Pole. Let's reverse our position and look at the effect of the Earth's rotation.

This effect appears clearly in figure 4-7. The figure is a view of the Earth as it would appear if you were looking down on the North Pole. Imagine that a gyroscope has been erected on the Equator at point A with its axis vertical (perpendicular) to the surface of the Earth, and that because the gyroscope has frictionless bearings and no erecting system you must rely on gyroscopic stability to keep it vertical. After a few hours, the rotation of the Earth will move point A to the position marked B.



12.148
Figure 4-7.—Apparent rotation at the equator.

The gyro still heads in the same direction in SPACE, but is no longer VERTICAL. Its axis is no longer perpendicular to the Earth's surface at that point. To anyone standing on the Earth, it appears to be leaning to the west. After 6 hours, when the Earth has made a quarter turn, the gyro will be horizontal, as at C. After 12 hours (at position D) it will have turned completely over and will be upside down. And after 24 hours, the gyro will have made a complete revolution.

In other words, the gyro is tilting WESTWARD at a rate of 15° per hour. The gyro, therefore, must be made to precess EASTWARD at 15° per hour.

When the gyro is vertical, the erecting system causes no precession. It affects the gyro only when the gyro is tilted. And so, if we were to rely on the erecting system to produce the required eastward precession, the gyro would always lean slightly to the west. It would NEVER be truly vertical, as it should be for efficient fire control. An error would always persist, being maximum at the Equator and gradually decreasing to zero at either pole. Therefore, you correct for the effect of the Earth's rotation at all times by applying to the gyro some force that will cause a steady eastward precession. This means that the top of the gyro axle must be pushed northward.

This can be done by extending a small arm northward from the top of the axle, and by hanging a weight on the north end of the arm (fig. 4-8).

Up to now, it has been assumed that the gyro is located at the Equator.

If the gyro were placed at the North or South Pole, the rotation of the Earth would have no tendency to move it out of the vertical. In this instance, the gyro's axis is parallel to the Earth's axis. Apparent rotation is about the gyro's spin axis and no effect will be observed. You would expect that at points on the Earth between the Equator and a Pole, the gyro would tilt westward at a speed LESS than 15° per hour. This is true, and figure 4-9 shows you why. If a gyro is set vertical at A, it will move to point B in 12 hours, and will tilt through an angle of 180 - (2 x latitude of A) = 90° (instead of through 180° as it would at the Equator).

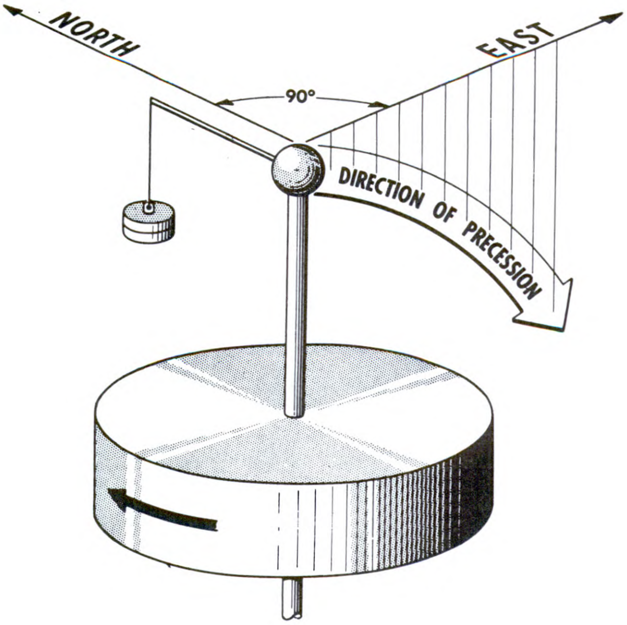


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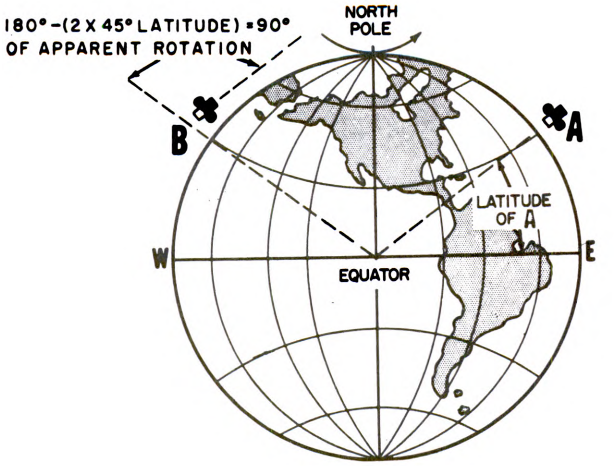
Figure 4-8.—Latitude correction weight.



12.150
Figure 4-9.—Effect of Earth's rotation at midlatitude.

This means that the precessional force should be decreased in higher latitudes. You can slow down the precession by moving the compensating weight inward on the arm, closer to the gyro axle (spin axis). The arm has markings on it to show you the correct position of the weight for any latitude.

GYRO APPLICATIONS

As mentioned previously, gyros may be classified according to their degrees of freedom: that is, a single-degree-of-freedom (restrained) or a two-degree-of-freedom (free) gyro. Gyros are also sometimes classified as to the orientation of the spin axis (horizontal or vertical) and according to their application, such as directional, stabilizing, and rate gyros.

DIRECTIONAL GYROS

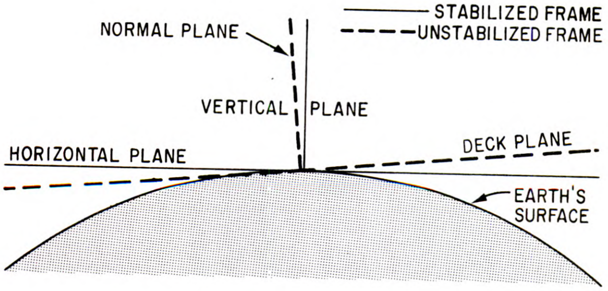
The directional gyro is a free, horizontal gyro that holds its position in azimuth (on the horizon) and is used to show any deviation from a desired heading (bearing). The basic gyro shown in figure 4-1 demonstrates the rotor and gimbal alignment of a directional gyro. This type of gyro is not compensated for the effects of the Earth's rotation and, thus, must be periodically leveled and set to the desired heading.

Directional gyros are used in conjunction with a magnetic compass for navigation purposes. They are also used on surface ships and submarines when near the Poles, where special navigation techniques are required.

STABILIZING GYROS

Stabilizing gyros are used to establish a fixed reference plane from which movement or displacement can be measured. In addition to the basic components of a free gyro, stabilizing gyros have pickoffs for detecting and transmitting any movement from the stabilized reference plane. The pickoff outputs are used as error detector inputs to servosystems which function to stabilize the equipment concerned.

All fire control systems employ stabilizing gyros. There are two reference frames involved in the solution of the fire control problem. One reference frame is made up of the horizontal plane, which is considered to be tangent to the Earth's surface at the ship's position, and the vertical plane, which is perpendicular to the horizontal plane (fig. 4-10). This is a fully stabilized frame, independent of ownship's roll and pitch motions. The other frame is made up of the deck plane of ownship and the normal plane, which is perpendicular to the deck plane. This frame is unstabilized and rotates with the ship's deck as it tilts. When the ship is on an even keel, the deck plane is in the horizontal plane and the two frames are coincident. If,



166.194
Figure 4-10.—Stabilized and unstabilized reference frames.

however, the ship rolls or pitches, the horizontal plane is not affected, but the deck plane follows the motion of the ship, and the two frames are no longer coincident.

Thus, the deviation of the deck plane out of the horizontal plane is caused by the roll and pitch motion of the ship. Pitch is the up-and-down motion of the ship's bow. The pitch angle is measured in the vertical plane through ownship's centerline (fig. 4-11). Roll is the motion of the ship as it rotates about the ship's centerline axis, 90° from the pitch motion. Roll is the angle between the vertical plane and the normal plane. The roll angle is measured where the two planes intersect in the deck plane along ownship's centerline. In fire control, a positive pitch occurs when the bow of the ship goes below the horizon. A positive roll occurs when the starboard side rises above the horizon.

The primary purpose of the stable element (stabilizing gyro) is to accurately measure the motion of the deck with respect to the line of sight (los). The component of deck tilt in the los is called the level angle (fig. 4-12), and the component across the los is called the crosslevel angle. A positive level angle occurs when the deck, in the vertical plane through the los, goes down. A positive crosslevel angle occurs when the deck on the righthand side of the vertical plane through the los rolls upward. The level and crosslevel angles are used to generate corrective signals to compensate for deck tilt out of the horizontal plane. The signals are used to establish a stabilized reference plane within the fire control system, and to help the radar tracking system stay on target.

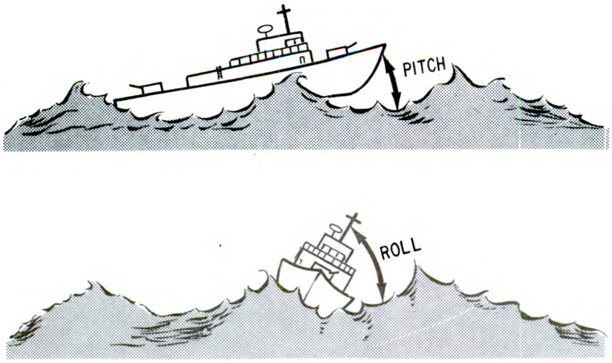


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Figure 4-11.—Roll and pitch motion of the ship.

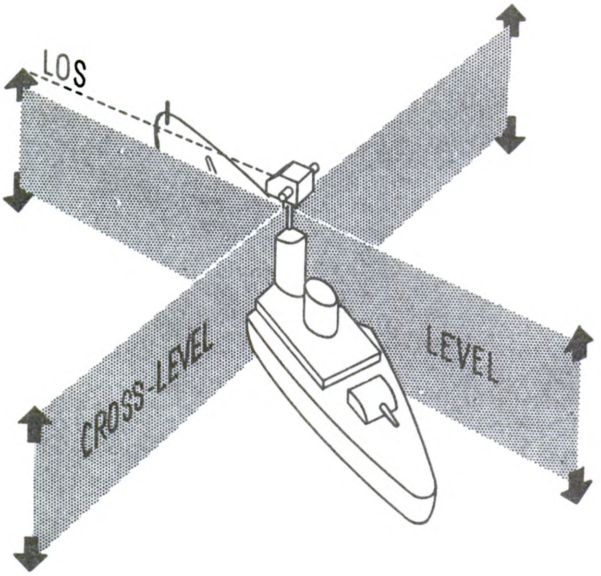

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Figure 4-12.—Level and crosslevel.

RATE GYROS

Rate gyros are used in fire control to detect and measure the angular rate of change of position of an object. The rate of change of an object can be defined as the speed or velocity with which an object is displaced from its original position to a new position.

The rate gyro is basically a single-degree-of-freedom gyro in that the gyro contains a mechanical system that consists of a spinning rotor and an associated gimbal system. It differs from other single-degree-of-freedom gyros in that the rotor is restrained by some means, usually a spring. This restraint harnesses the work of the rate gyro by returning the gyro to a null or neutral position after each precession. This provides the system with an accurate reference point.

A simplified rate gyro with a spring restraint is shown in figure 4-13. The rate of movement

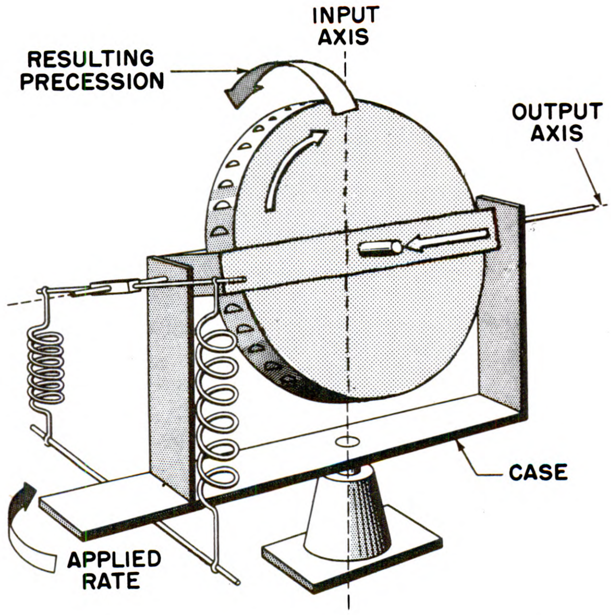

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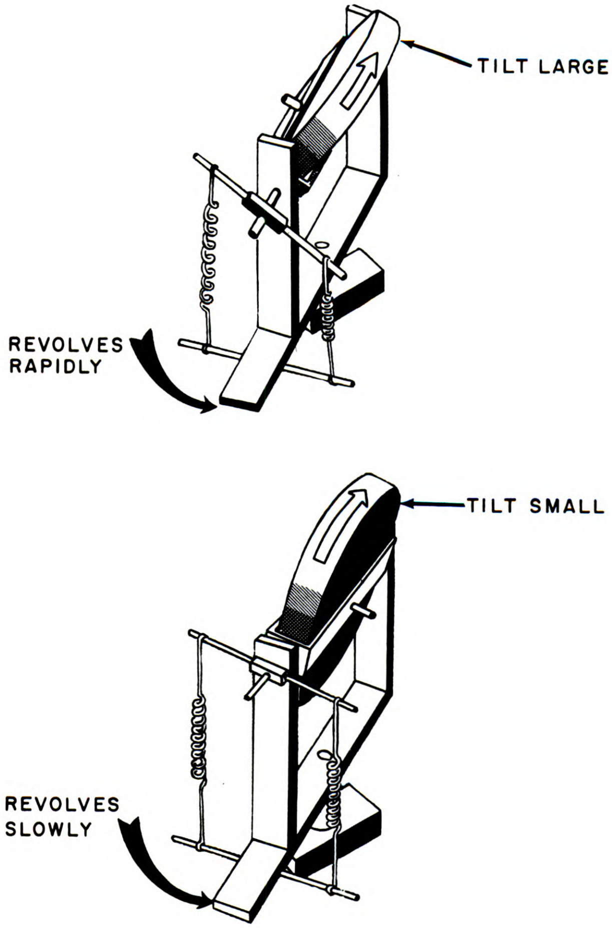
Figure 4-13.—Spring-restrained rate gyro.

or applied rate is about the gyro's input axis in the direction shown. This is equivalent to placing a force parallel to the output axis on point F. The resultant precession is felt about the output axis where we would mount our pickoff or measuring device.

We can illustrate the principle of the rate gyro by comparing the two identical gyros in figure 4-14. In the gyro at the bottom of the figure, we rotate the system slowly about its input axis and note a small amount of precession. In the gyro at the top of the figure, we revolve the gyro more rapidly about the input axis and notice a proportionally larger amount of precession even though we move the gyros the same total distance. This illustrates that the precession is proportional to the rate of change of position of a rate gyro.

STABLE ELEMENT

If you refer back to figure 4-2, you will recall that all fire control systems need stabilization, and that a gyro is used to accomplish this.



12.152

Figure 4-14.—Precession is proportional to the rate of turn.

Throughout this chapter, you have been given the basic properties and components of gyros. Now, let's put it all together and see how a gyro functions in a typical fire control system.

In gun fire control, we call the stabilizing unit a stable element. As its name implies, the stable element employs a stabilizing gyro. The primary purpose of the stable element is to accurately measure any deviation of the ship's deck from the horizontal plane. These measurements are sent to the fire control computer to form a stationary foundation from which to solve the fire control problem. These measurements are also sent to the gun director, or radar antenna, or optical equipment, depending upon the fire control system, to stabilize these units of the fire control system.

THE GYRO

The heart of a stable element is the gyro. This is the shaded ball in figure 4-15. It consists of the gyro rotor and an aluminum ball. The ball is held within a gimbal by a pair of wires, called torsion wires. The gimbal, in turn, is held to the walls of a tank, called a flotation tank, by a second pair of torsion wires. The flotation tank is filled with a liquid of sufficient density at its operating temperature to float the ball. Therefore, the ball is held in a state of neutral bouyancy. Consequently, the torsion wires do not carry any load, but only act as axes to hold the ball in place, relative to the gimbal and the flotation tank. But if the flotation tank were rotated, the ball (and gyro rotor) would twist on the torsion wires, and be out of alignment with the flotation tank.

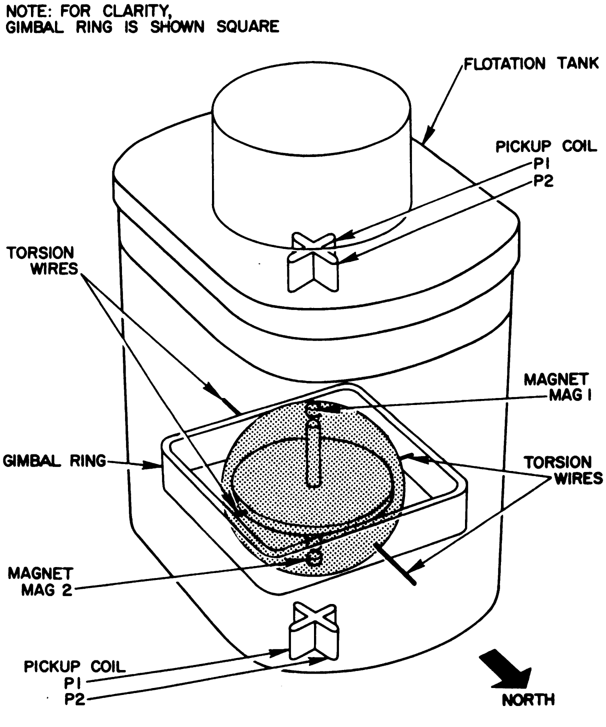


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Figure 4-15.—Phantom view of sensitive element.

Two electromagnets are mounted on the gyro wheel axle (fig. 4-15). The position of the magnets is determined by the gyro wheel spin axis. Two crossed-E pickup coils are fixed inside the flotation tank, close to the magnets, so that the magnets can induce voltages in the coils. The position of pickup coils is determined by the motions of the flotation tank. When the magnets (or gyro wheel spin axis) are centered on the pickup coils through the top-to-bottom reference line of the flotation tank), the voltages induced are equal and will cancel each other. When the coils are not centered on the magnets however, the voltages induced in the coils do not cancel, and there is an output. The amplitude of the output voltage is proportional to the amount of tilt or, more exactly, to the angle between the spin axis of the gyro and the reference line of the flotation tank. The phase of the pickup coil output voltages depends on the direction of the tilt.

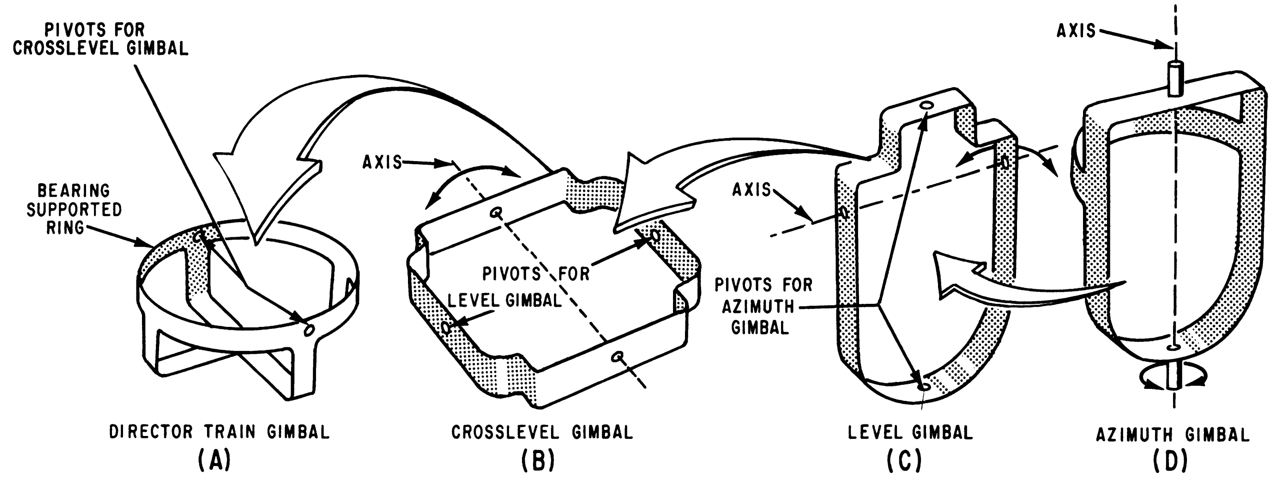
In order for the stable element to function properly, the spin axis of the gyro must be aligned with the vertical plane. The flotation tank is mounted in a gimbal system. Once we know the gimbal system, we can show how the gyro is brought to the vertical and how the output signals from the pickup coils are used.

GIMBAL SYSTEM

As with any of the basic gyros that we have discussed so far, the stable element gyro needs gimbals so that the spin axis may rotate freely. The job of these gimbals is to bring the gyro's spin axis to the vertical plane and keep it there. The gimbals are equipped with synchros and servomotors so that they can drive the sensitive element (and gyro ball) to the correct position. Let's take a look at them, and see what they do.

Director Train Gimbal

The director train gimbal (fig. 4-16A) is bearing mounted to the frame of the stable element, and supports the other gimbals. This gimbal can rotate through 360° in train, but is driven by a servo so that it is always aligned with the train angle of the director. This angle, of



166.30

Figure 4-16.—Stable element gimbals.

course, is the line of sight (los). Once the director train gimbal is in the los, other gimbals mounted "upon" it will be properly oriented to do their jobs. This brings us to the next gimbal. The two holes in the director train gimbal are the pivot points for the crosslevel gimbal.

Crosslevel Gimbal

The crosslevel gimbal (fig. 4-16B) pivots inside the director train gimbal. It is positioned about its axis by a servo. Any movement of the crosslevel gimbal is a measure of the tilt of the ship's deck across the los (crosslevel). Crosslevel was explained earlier, in figure 4-12. The signal that drives the crosslevel gimbal servo comes from the gyro pickup coils, and from devices called pendulums, which we will discuss in the next topic (the erecting process).

Level Gimbal

The level gimbal (fig. 4-16C) carries the azimuth gimbal. It also pivots inside the crosslevel gimbal. It is positioned about its axis by a servo whose input comes from the gyro pickup coils and pendulums. Any movement of the level gimbal is a measure of the tilt of the ship's deck in the los (level). Level was explained earlier, in figure 4-12.

Azimuth Gimbal

The azimuth gimbal (fig. 4-16D) holds the sensitive element (gyro). This gimbal, like the director train gimbal, is not used to position the gyro rotor axis in the vertical plane. Instead, it is used to keep the sensitive element pointed in a certain direction. In this case, the azimuth gimbal points the sensitive element towards true north (shown by the dark arrow in fig. 4-15). No matter which way the ship turns, or which way the director train gimbal turns, the signal driving the azimuth gimbal servo will keep the gyro pointed to true north.

If you refer back to figure 4-8, you will remember why the gyro has to be pointed to true north. With the sensitive element pointed to true north, a correction can be applied to compensate for apparent tilt of the gyro. You will remember that apparent tilt is caused by the Earth's rotation, and varies at different latitudes. Therefore, the correction applied to the gyro is called latitude correction. You will see how this is accomplished later in this chapter.

ERECTING PROCESS

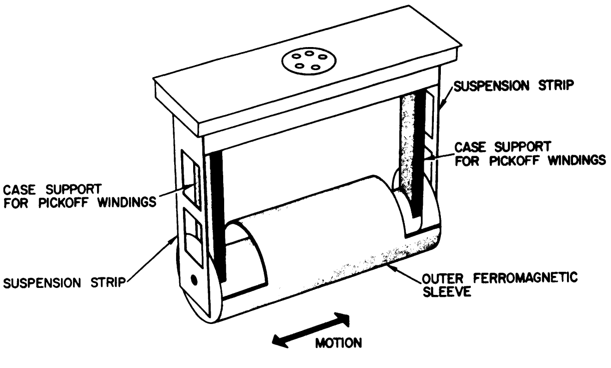
So far, our stable element has a gyro and a gimbal system. When the stable element is started, the gyro spin axis should go to the vertical plane and stay there. One logical way to accomplish this is to use the effects of gravity and devices called pendulums, which were discussed earlier.

Basically, you can consider a pendulum as an electromechanical plumb bob. The pendulum consists of a concentrated mass, called a bob, supported by a flexible suspension strip (fig. 4-17). Pendulum construction limits the motion of the bob to one plane. The bob can move along the axis supported by the flexible strip. Hence, if the pendulum mounting is tilted along the pendulum's sensitive axis, the bob will move. The amount of motion is determined by the unbalanced force, which is proportional to the degree of tilt of the mounting. The direction of the bob's motion is determined by the direction of the tilt.

Pendulum motion produces an electrical signal. The amplitude of the signal is proportional to the amount of tilt of the pendulum. This signal is used to drive the servos attached to the level and crosslevel gimbals. Now let's see how pendulums can erect the gyro.

Two pendulums are mounted on the azimuth gimbal and arranged at right angles to each other (one along the north-south axis and the other along the east-west axis).

Two additional pendulums are mounted on the level gimbal. These pendulums are also arranged at right angles to each other (one in the los, the other across the los).


SUSPENSION STRIP
CASE SUPPORT FOR PICKOFF WINDINGS
CASE SUPPORT FOR PICKOFF WINDINGS
SUSPENSION STRIP
OUTER FERROMAGNETIC SLEEVE
MOTION

166.31

Figure 4-17.—Simplified pendulum without case.

These pendulums are the vertical-seeking devices of the stable element. If the gyro rotor axis is not in the vertical plane, it is because the azimuth and level gimbals are tilted. Being tilted, the pendulums will produce signals to drive the level and crosslevel gimbals into the horizontal plane, at which time the gyro spin axis will reach the vertical plane.

Because the gyro tends to remain fixed in space as the servomotors drive the gimbals, the torsion wires of the gyro suspension system become twisted and exert torque on the gyro. The gyro will precess at right angles to the applied torque, and its spin axis will follow a decreasing spiral path to the vertical plane.

Once the gyro spin axis is in the vertical plane, the pendulums on the level gimbal are cut off, and only the azimuth gimbal pendulums, along with the magnets and pickup coils of the sensitive element, are used to keep the gyro erected properly.

LATITUDE CORRECTION

It has been shown how the rotation of the earth from west to east causes the gyro to precess westward away from the local vertical plane. This is called apparent tilt of the gyro. To prevent apparent tilt, a torque is applied to the gyro to cause an easterly precession. The precession rate depends on the latitude, and is maximum at the equator.

A latitude correction voltage is introduced into the signal circuit of the north-south azimuth gimbal pendulum. The amount of voltage is determined by the setting of a potentiometer. The potentiometer has a dial that is scaled in degrees of latitude, and is set to the ship's latitude position.

The introduced latitude correction voltage causes the level and crosslevel servos to drive to null the signal. If the azimuth gimbal is vertical and the gyro magnet is in the center of the pickup coils, the voltage will offset the gyro spin axis from the center of the pickup coils. The servos drive to eliminate the offset. Since the gyro is rigid, this results in the gyro's torsion wires being twisted. The wire twist will couple a torque to the north-south axis of the gyro and cause a steady and constant precession of the gyro eastward. This is desired to correct for the earth's rotation.

SUMMARY

There are many more complicated components and circuitry in a fire control stabilization unit. It is not important for you to learn them at this time. If you understand the basics of gyros and basically how a fire control stable element works, you have accomplished what this chapter has tried to teach you.

CHAPTER 5

THE GUN FIRE CONTROL PROBLEM

INTRODUCTION

By definition, fire control is the technique of delivering effective fire so as to damage or destroy a selected target. This would be a simple task if you were shooting at bottles with a rifle from 50 feet away.

In gun fire control, the target is often many miles away, and the gun is very large. This means it takes a long time for the projectile to reach the target and gives nature time to work on the projectile's trajectory. Gravity will pull down on the projectile, winds will blow it off course, and the spinning action caused by the gun's rifling will cause it to drift (curve) in the direction of the spin.

There are many other difficulties involved in the fire control problem. The ship rolls and pitches, making it more difficult to keep the sights on the target. Frequently the target is moving, and will be far away from an anticipated point in space by the time a projectile arrives there. Once the projectile has left the gun muzzle, nothing further can be done to effect its course. The gun's fire control problem must be solved before the gun is fired.

The pieces of equipment that are almost completely automatic have been integrated to make up gun fire control systems (GFCS). Automatic equipment is complex, since it must substitute mechanical operation for human judgment. Consequently, knowledge of equipment functions and operations has become more demanding. The mathematics of the gun fire control problem are rapidly solved by the fire control computer, shown in figure 5-1.

This chapter will divide the problem of gun fire control into logical subject areas and examine the elements of the problem in these areas. Hence, this chapter will provide you with the background knowledge that is a prerequisite to your understanding of a modern GFCS.

THE SCIENCE OF BALLISTICS

Ballistics is the science of the motion of projectiles. It is divided into two branches, interior and exterior ballistics. Interior ballistics is that branch of the science which deals with the motion of the projectile while it is in the gun. The initial velocity (iv) of the projectile is a result of the forces involved in the general term interior ballistics. Exterior ballistics pertains to the projectile after it leaves the gun.

The curved path a projectile travels in passing from the gun's muzzle to the point of impact is called its trajectory. The curvature of the trajectory is the result of forces acting on the projectile in flight. If it were not for these forces, the projectiles would travel in a straight line. Obviously, knowledge of the trajectory a projectile will take is necessary to position a gun correctly.

INTERIOR BALLISTICS

Interior ballistics deals with the mechanical and ballistic condition of the gun. A satisfactory gun must meet certain requirements. For instance, it must withstand the pressures developed by the propelling charge. In addition, it must discharge the projectile at the desired velocity. (The projectile's velocity at the instant

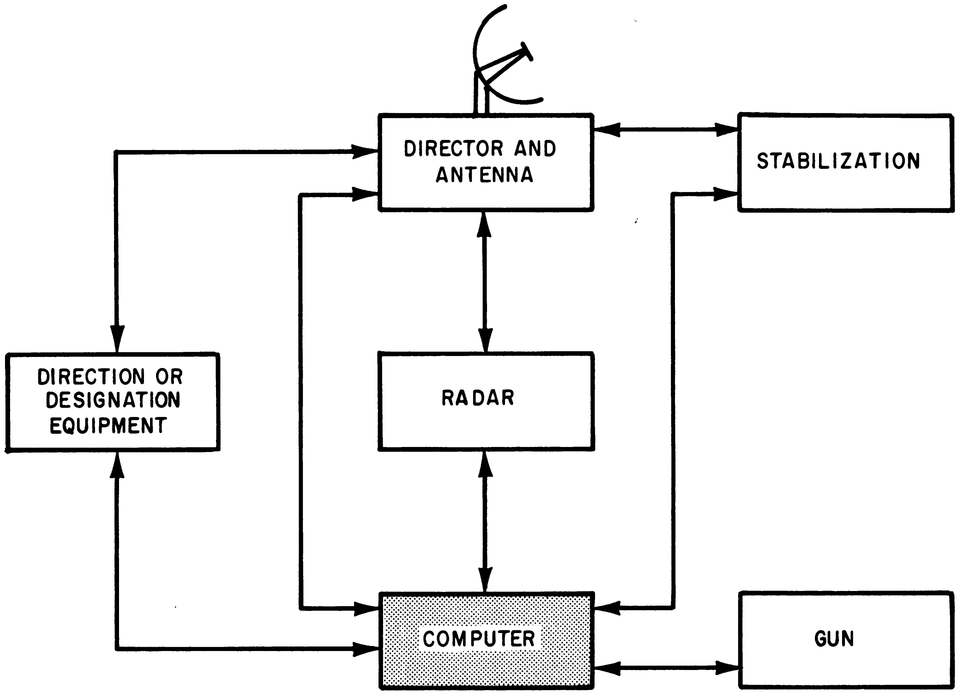


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Figure 5-1.—Computers are used to solve the mathematics of the gun fire control problem.

it leaves the muzzle is called either muzzle velocity or initial velocity.)

The initial velocity of the projectile must be known in order to predict its trajectory. Initial velocity is determined by the gun, the projectile, and the propelling charge. Under controlled conditions a fixed combination of these factors will produce the same initial velocity at each firing. The controlled conditions are: (1) a new gun with no wear and (2) a standard projectile and propelling charge. Following is a brief explanation of the factors affecting the initial velocity of a projectile.

Let's start with the gun. Basically, a gun is a tube capable of withstanding the explosion of a powder charge (propellant), and of controlling the propelling force so as to discharge the projectile at high velocity in a desired direction. Figure 5-2 shows a cutaway view of a gun. The barrel is a tube which is sealed at one

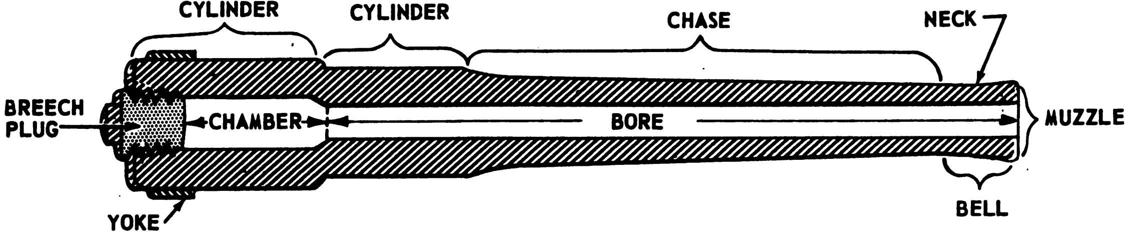

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Figure 5-2.—Cross section of a gun.

end by the breech mechanism, after the projectile and powder charge have been loaded into the gun chamber. The projectile engages the gun bore and seals the other end of the chamber. When the powder charge is ignited, it produces gas at extremely high pressure. This pressure forces the projectile through the gun bore. A soft metal band, called the rotating band, on the projectile is enmeshed with the rifling in the gun bore (fig. 5-3). A twist in the rifling as it extends down the bore causes the projectile to rotate as it passes through the bore. The rotary motion causes the projectile to spin in flight. This spinning motion keeps the projectile from tumbling end-over-end, and makes its trajectory predictable. We will come back to projectile spin when we discuss exterior ballistics.

Erosion of the gun bore is caused by the intense heating of a thin layer of metal at the surface of the bore, and by the rush of hot gases over this surface. Erosion results in a gradual enlargement of the bore. It begins at the rear of the bore and extends farther down the bore as the gun is used. The lands are eroded about twice as fast as the grooves (fig. 5-3).

The life of the gun is determined by the number of service rounds that may be fired through it before it loses its accuracy.

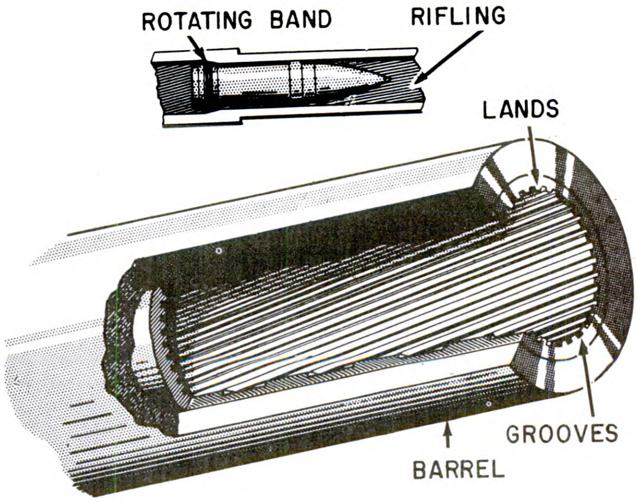

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Figure 5-3.—Rifled bore and projectile.

All the factors previously described affect the initial velocity of the projectile.

More will be said about initial velocity in the next section, because it is common to both interior and exterior ballistics.

EXTERIOR BALLISTICS

Exterior ballistics starts with a projectile traveling at a known speed and in a known direction. This direction, called the LINE OF FIRE, for all practical purposes coincides with the center line axis of the gun bore. Once the projectile leaves the gun, you have no further control over its trajectory. Forces of nature act on the projectile in flight to alter the trajectory. Therefore, to hit a target it is necessary to know these forces and to compensate for their effects by changing the gun's position before firing. For example, if it is known that the projectile is going to curve to the right, the gun should be trained to the left. If it is known that the projectile is going to curve downward, the gun should be elevated.

The ultimate purpose of all the fire control gear-directors, radars, synchros, servos, computers, and power drives—is to find the right position for the gun barrel to make the projectile fall where desired, and to put the gun in that position.

In this discussion of exterior ballistics, a particular gun, or type of projectile, or initial velocity will not be specified. The factors involved are physical, hence natural, and their effects are felt in all gun-projectile-velocity combinations. Two of these factors that are always present are the pull of gravity and the resistance of the atmosphere. Their effects on a trajectory can best be seen by showing a theoretical trajectory in which they are absent. This will have to be a hypothetical case located in outer space.

Hypothetical Case

If you were far enough in outer space and picked up a projectile and then let go of it, the projectile would stay where you put it. Out in space objects have little or no weight—there are no bodies close enough to exert an appreciable gravitational pull. Since there is no atmosphere in outer space, there is no air resistance to hinder the flight of a projectile.

So how are you going to lay (aim) the gun? The answer is provided by one of the fundamental laws of physics—Newton's first law of motion. This law states that any moving body will continue to move in a straight line at the same speed until something interferes with it. When the projectile shoots out the muzzle of your "space" gun at a speed of 2700 feet per second, there is nothing to interfere with it. It will simply continue to travel at this speed along the line of fire indefinitely or until it hits something.

That would make fire control pretty easy. You would just sight the gun barrel at the target and press the firing key. If the enemy were on the line of the gun bore axis and stayed there, there would be a hit, no matter the distance.

Problem of Gravity

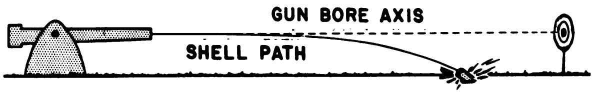
On Earth things are not so easy. Here, if you lift a projectile and then let go of it, it will fall to the ground. This, of course, is due to the force of gravity. Gravity is always an attracting force, acting perpendicular to the surface of the Earth, which tends to pull all objects toward the Earth.

A falling body, generally speaking, falls faster and faster the longer it falls. In each second of fall, an object increases its speed by about 32.2 feet per second. (The acceleration due to gravity is usually called g.)

Effect of Gravity in a Vacuum

Suppose you could line up the axis of a gun bore in a vacuum and fire it straight at a target at zero elevation. As before, the projectile will continue to travel in the same direction and at the same speed unless something interferes with it. In this case (fig. 5-4), that something is gravity.

As soon as the projectile leaves the gun it starts to fall, just like any other object. The projectile, however, is traveling forward and falling at the same time. The projectile has two forces acting on it—the momentum imparted by the forward thrust of the gun's propulsion system, and the pull of gravity. The path of the projectile, as a result of these two forces, is a curved trajectory.



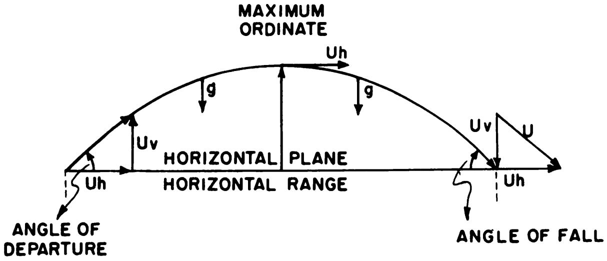
12.1

Figure 5-4.—Projectile motions.

The forward momentum of the projectile tends to keep the trajectory a straight line in accord with Newton's first law of motion. Gravity, however, starts the projectile falling. The constant pull of gravity causes the falling motion to accelerate, and the downward slope of the trajectory to increase.

If the projectile is going to curve downward when the gun is fired, the gun must be elevated. But the question is, how much? Suppose the gun is elevated above the horizon by some angle, as shown in figure 5-5. This angle, the gun elevation above the horizontal, is known in ballistics as the ANGLE OF DEPARTURE. In ballistics the Earth's surface is assumed to be flat, and it is used as the horizontal reference plane.

The projectile's momentum will tend to keep the trajectory in the line of fire. Since the angle of departure is elevated above the horizontal, the projectile's momentum can be divided into



12.2

Figure 5-5.—Vacuum trajectory.

horizontal and vertical components. The horizontal component of the projectile's momentum causes the projectile to travel across the surface of the Earth. The vertical component causes the projectile to ascend above the surface of the Earth.

The percentage of the projectile's momentum contained in each of the components is a function of the angle of departure. This factor will be considered later. The percentages for the angle in the figure are indicated by the length of the vectors. The vector representing the total momentum is labeled U, while the horizontal component is Uh, and the vertical component Uv.

The vertical component, Uv, is greater by far than the pull of gravity (g), and the projectile's trajectory will be upward. But because of the constant gravitational pull, Uv will diminish as the projectile climbs. Since g is acting on the projectile continuously, the downward deviation from the line of fire becomes greater with the passage of time.

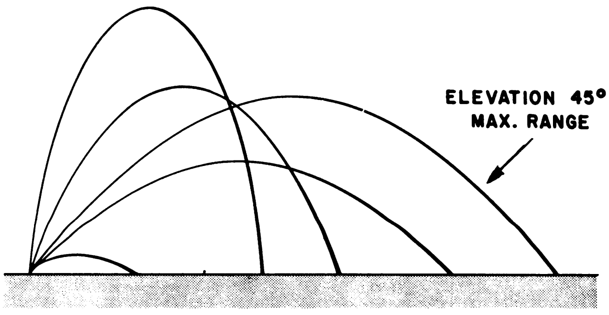
Eventually g will become equal to the diminishing Uv; at this time the projectile will stop climbing. It is then at the highest point, called the maximum ordinate, of its trajectory. From this point, it begins to fall. The projectile, as it falls, is accelerated by g. Since g is constant, it will add the same amount of velocity to the projectile in the falling portion of the flight as is subtracted in the climbing portion of the flight. Consequently, the velocity at which the projectile strikes the Earth will equal the initial velocity.

The curvature of the trajectory is the reaction to the three vectors Uh, Uv, and g. The horizontal component, Uh, is not affected by gravity and so is constant throughout the trajectory. Remember that we are in a vacuum, and that gravity is the only retarding factor. Since Uh is constant, the projectile will travel an equal distance in the horizontal plane in each second of the time of flight. This fact, coupled with the fact that g also is constant, means that the maximum ordinate (height of the projectile) will be in the exact center of the trajectory, and that the two halves of the trajectory's curve are identical. Hence the angle at which the projectile lands, called the ANGLE OF FALL, is equal to the angle of departure. The shape of the trajectory is a curve known as a parabola.

The distance from the gun to the point where the projectile hits the ground is called HORIZONTAL RANGE. The range obtained in a vacuum is determined by the initial velocity of the projectile and the angle of departure of the gun. For a given angle of departure, an increase in initial velocity will increase range, while a decrease in initial velocity will decrease range. This is obvious, but the variation in range due to a change in the angle of departure needs an explanation.

It can be seen from figure 5-5 that the vectors Uv and Uh vary as functions (sine and cosine, respectively) of the angle of departure. As the angle is increased, the vertical component Uv will increase. Consequently, it will take a longer time for gravity to stop the upward motion of the projectile and to pull the projectile back to Earth. Hence the maximum ordinate will increase as the angle increases, and the time of flight will become longer.

The horizontal component, Uh, will decrease with an increase in the angle of departure. However, at angles of departure between 0° and 45° an increase in the angle will result in an increase in the horizontal range, due to the longer time of flight. Maximum horizontal range in a vacuum would be obtained at an angle of departure of 45°. Typical trajectories in a vacuum are shown in figure 5-6. Note in the



12.3

Figure 5-6.–Typical vacuum trajectories for different angles of departure.

figure that at angles of departure above 45°, the maximum ordinate is higher and the horizontal range is shorter. At high angles most of the projectile's momentum is in the vertical trajectory, and although the time of flight becomes longer, the reduction in the horizontal component of the projectile's momentum will shorten the horizontal range.

High angle fire is not often used on surface targets.

High angle fire, with its high maximum ordinate, is extremely important in antiaircraft (AA) gun fire.

The characteristics of a vacuum trajectory in Earth's gravity field can be summarized as follows:

1. Striking velocity equals initial velocity
2. Angle of fall equals angle of departure
3. Maximum ordinate is in the center of the trajectory
4. The projectile travels a symmetrical curve called a parabola
5. Maximum range is obtained with a 45° angle of departure

A comparison of the hypothetical space shot and the vacuum trajectories will indicate the effect of gravity. You will never fire in a vacuum, and, therefore, these trajectories are hypothetical.

Now, by adding the air in the Earth's atmosphere, actual firing conditions can be projected.

Effect of Air

When the projectile is traveling through air, it takes a different path from the one it would follow in a vacuum.

Air resists the motion of any body passing through it. That is, when any body is moving though the air, the air will set up a force pushing backward in the line of motion of the body. This force keeps slowing the movement of the body, and a certain amount of speed is lost during each second of a projectile's flight.

With a little thought, you can see what air resistance does to the shape of a vacuum trajectory. When first fired the projectile has the greater momentum, hence the greater resistance to any change of its motion. The longer the projectile travels through the air, the slower it goes.

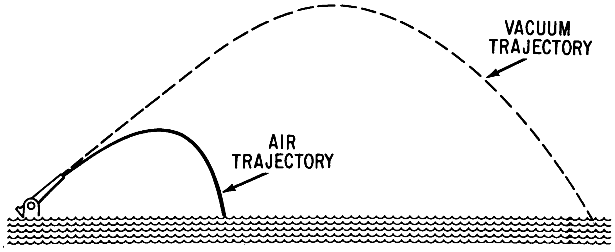
Consequently, the horizontal distance traveled is smaller for each consecutive second of flight. Naturally the vertical component of the projectile's velocity is also affected by air resistance. The vertical component, however, is accelerated by gravity during the descent of the projectile. Therefore, the air trajectory will be greatly modified from the vacuum trajectory at its far end, where the horizontal velocity is reduced.

In figure 5-7 you can see how the trajectory of a projectile fired in air differs from that of a projectile fired at the same angle of departure in a vacuum. Notice the steepness of the descending curve in the air trajectory. And note that the maximum ordinate is not at the middle of the trajectory, but is nearer the point of impact than it is to the gun. Notice also that the range of the projectile in air is much less than its range in a vacuum.

In order to give a projectile the same range in air that it would have in a vacuum, the gun must have a greater elevation.

If the elevation were already set for maximum range (45°), an equal range could not be achieved.

A peculiar thing about air resistance is that it increases rapidly as the speed of the body increases. Roughly, when the speed doubles, the retardation of the projectile becomes more than



12.4

Figure 5-7.—Comparison of vacuum and air trajectories for same angle of elevation.

four times as great. Thus, if a projectile traveling at 1000 ft/sec were retarded 100 ft/s every second, a projectile traveling 2000 ft/s might be slowed as much as 400 ft/s every second.

The DENSITY of the air determines the amount of resistance of the air to the projectile. Dense air will slow the travel of a projectile more than thin air, and this complicates the problem quite a bit. Air density depends on temperature and barometric pressure and these values are changing all the time. Moreover, the density is less at higher altitudes than it is at sea level. Since the trajectory rises high into the air for a long-range shot, the projectile will be retarded less during each second that it is in the upper portion of the trajectory than when it is at the low points.

Another thing that affects the shape of the trajectory is the WEIGHT of the projectile. The heavier the projectile, fired at the same initial velocity, the more momentum the projectile has and the less its trajectory is affected by air resistance.

The SHAPE of the projectile also makes a difference. Obviously, the bigger around the projectile is, the more air will push against it. A pointed nose makes it easier for the projectile to push its way through the air and reduces resistance. Boattailing or tapering the after end of the projectile reduces the drag resulting from air turbulence behind the projectile, which also reduces resistance.

The effect on the air resistance resulting from the shape of the projectile is expressed by a quantity called the COEFFICIENT OF FORM. The data for such a drag coefficient or resistance curve are computed from measurements obtained by experimental firings of standard projectiles at the Naval Weapons Laboratory, formerly called the Naval Proving Ground.

Drift

Naval guns are rifled to give a spinning motion to the projectile. The spinning projectile assumes the properties of a gyroscope. The gyroscope actions tends to keep the projectile pointed along the trajectory, and prevents it from tumbling. This makes the projectile almost rigid in its trajectory, and ensures that it will land point first. It is this property of rigidity which makes the trajectory predictable.

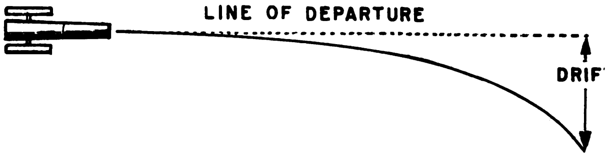
In addition to its useful effect, gyroscopic action causes the harmful effect of drift (fig. 5-8). Notice in figure 5-8, that the drift increases with range. Drift is always to the right in any gun with right-hand rifling. Right-hand rifling gives a clockwise spin to the projectile.

The exact causes of drift are complicated, and beyond this discussion. It is enough to say that drift is the result of the interaction of gravity and air resistance on the spinning projectile. Fortunately a projectile drifts by a definite amount. This has been determined by experimental firings.

To compensate for projectile drift to the right, the gun must be trained to the left. The question is how much? As you can see in the figure, the overall effect of drift is a linear deviation measured at the target. The gun trains in an angular motion, so the linear value must be converted to an angular value. The method used to convert the values will be discussed later in the chapter.

Wind

If you have ever played football on a windy day, you are familiar with the effects of wind on an object in flight. Depending on the direction and velocity of the wind, your well-aimed forward pass may have curved to the right or left, or fallen short of or beyond the point where you wanted it to land. Wind has exactly the same effect on a projectile in flight. If the wind blows from the left, the projectile will turn to the right, and vice versa. If the projectile is headed into the wind, its range will be decreased; and if it travels with the wind, its range will be increased. You can see that the



12.7

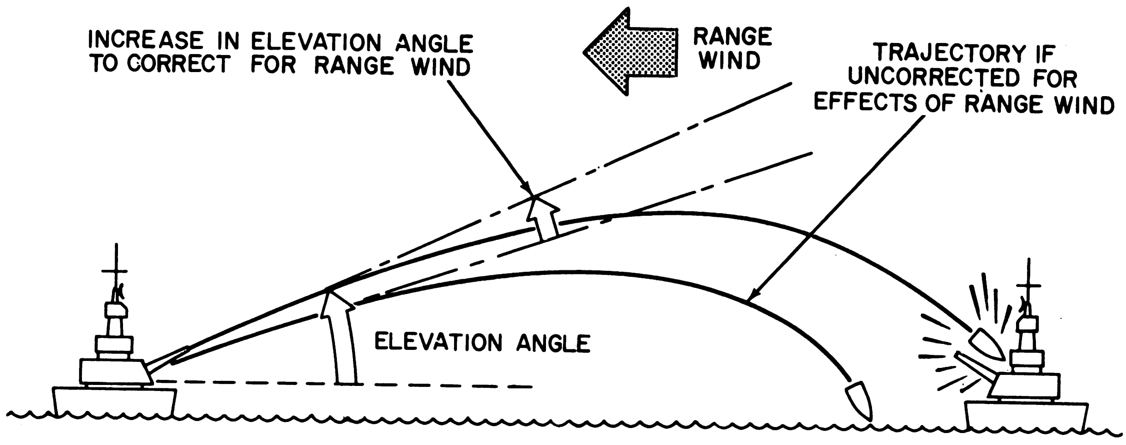
Figure 5-8.—Effect of drift.

effects of wind must be considered in the solution of the fire control problem.

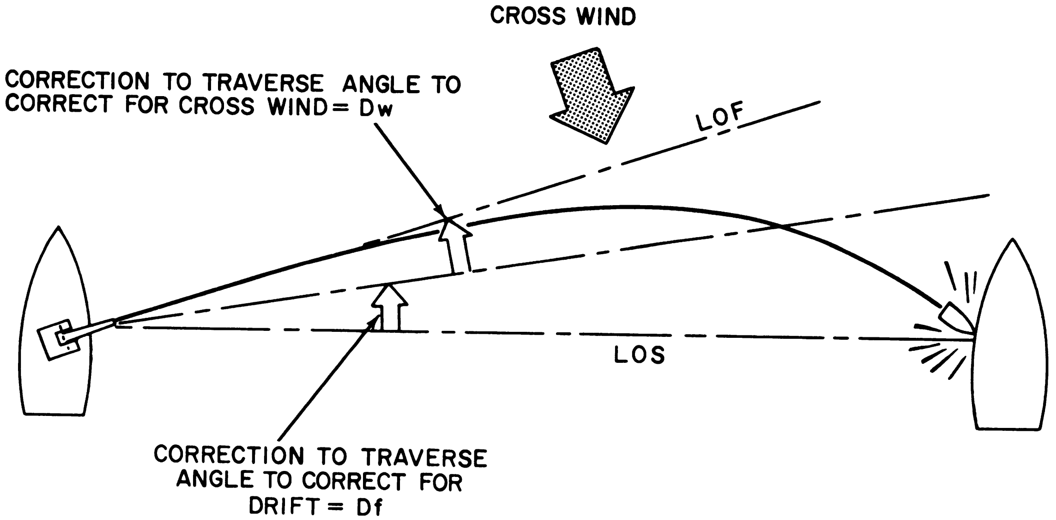
When the projectile is first fired, it is traveling at such high speed that the wind has very little effect. As the projectile slows down during its flight, the wind affects the projectile's course more and more. Hence, the longer a projectile remains in flight, the greater the effect of the wind and thus, wind deflection increases with range.

Two other factors which affect the amount the projectile deflects are wind speed and projectile size. Obviously the greater the wind velocity, the greater its effect on the projectile. Also, as was true for deflection due to drift, large projectiles have more initial momentum (weight times velocity) and can therefore resist the effects of wind better than small projectiles.

Refer to the figure 5-9. If the wind is blowing along the line of fire, either with or


INCREASE IN ELEVATION ANGLE TO CORRECT FOR RANGE WIND
RANGE WIND
TRAJECTORY IF UNCORRECTED FOR EFFECTS OF RANGE WIND
ELEVATION ANGLE

CORRECTING FOR THE EFFECTS OF RANGE WIND


CROSS WIND
CORRECTION TO TRAVERSE ANGLE TO CORRECT FOR CROSS WIND= Dw
LOF
LOS
CORRECTION TO TRAVERSE ANGLE TO CORRECT FOR DRIFT= Df

CORRECTING FOR THE EFFECTS OF CROSS WIND

166.197

Figure 5-9.—Corrections for the effects of wind.

against the projectile, it is called range wind. If the wind is blowing at right angles to the line of fire, it is called cross wind. Range wind is compensated for by increasing or decreasing gun elevation angle. Corrections for cross wind are made to the train angle separately from corrections for drift.

If the wind always blew in line with, or at right angles to the line of fire (lof), it would be a relatively simple matter to compute the corrections required when wind velocity was known. Usually, however, the wind blows at some angle to the line of fire. In order to correct for range and cross winds, it is necessary to resolve the true wind into components in line with, and perpendicular to the lof, as shown in figure 5-10. When this is done, each component can be treated individually and the proper gun setting adjustments made.

Corrections for the effects of wind are only approximate because wind speed and direction are usually different at various altitudes. For instance, the wind might be blowing from the north on the surface, and from the south at an altitude of 6000 feet. In such a case, the projectile will be affected differently at various levels of flight.

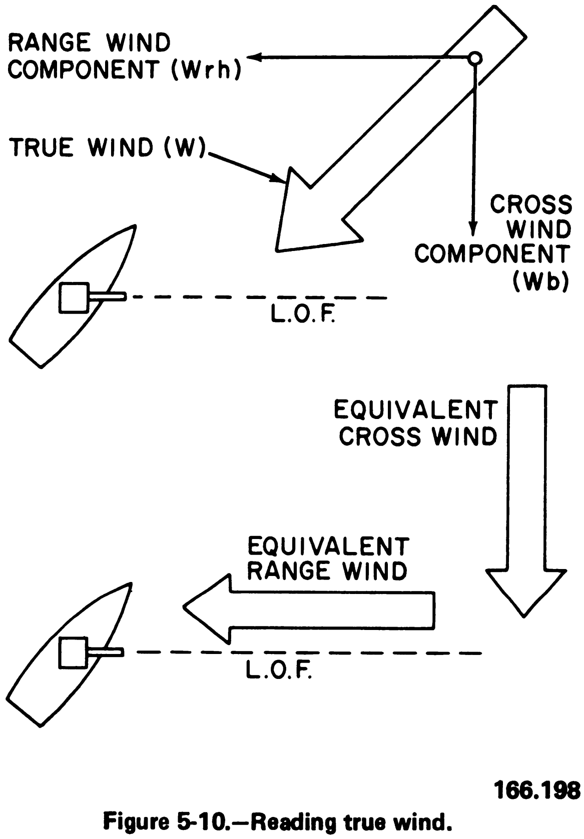


Figure 5-10.—Reading true wind.

Wind conditions at different altitudes are determined by observations from an airplane or by observing the movements of a small ballon. If it is found that the projectile's trajectory will take it through winds which move in opposite directions, a "weighted ballistic wind" must be used to compute gun setting corrections. This ballistic wind makes allowance for variations in wind velocity and direction, and for variations in air density at different altitudes. In solving the fire control problem, weighted ballistic wind is the most effective wind compensation.

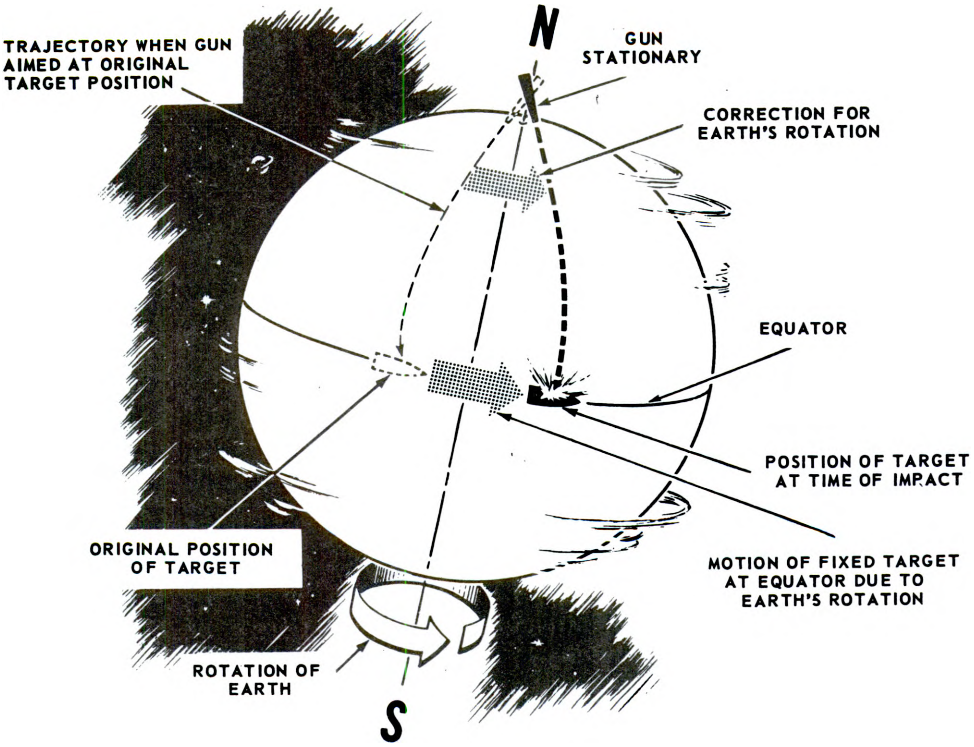
Another factor which must be considered is ownship's wind. As a ship moves, it creates a wind across its deck. This wind is called ownship's wind. Just as ownship's speed is combined with projectile iv, ownship's wind must be combined with true wind. The resultant, called apparent wind, is used in the solution of the fire control problem.

Earth's Rotation

In our discussion so far we have assumed that the Earth is flat and does not rotate. For ranges up to about 20,000 yards or so, such an assumption does not cause any serious effect on the flight of a projectile. At longer ranges, however, the effect of the Earth's rotation or, as it is sometimes called, the Coriolis force, has a serious effect.

An object, in motion above the surface of the Earth tends to turn toward the right in the Northern Hemisphere and toward the left in the Southern Hemisphere. This deflection to the right or left is an effect of two motions: the rotation of the Earth and the movement of the object in relation to the Earth's surface.

Suppose that you had a gun at the North Pole (fig. 5-11) which could fire a projectile far enough to reach a target at the Equator. Because the Earth spins on an axis through the North Pole, the gun would be stationary. But the target


TRAJECTORY WHEN GUN AIMED AT ORIGINAL TARGET POSITION
N
GUN STATIONARY
CORRECTION FOR EARTH'S ROTATION
EQUATOR
POSITION OF TARGET AT TIME OF IMPACT
MOTION OF FIXED TARGET AT EQUATOR DUE TO EARTH'S ROTATION
ORIGINAL POSITION OF TARGET
ROTATION OF EARTH
S

12.10

Figure 5-11.—Effect of Earth's rotation.

would be moving at a velocity of about 1000 miles per hour, since a fixed point on the Equator has that velocity due to the Earth's rotation. If you aimed the gun at the target and fired, the target would move several miles during the time the projectile is in flight, and the projectile would land where the target had been at the instant of firing. In order to score a hit it is necessary to "lead" the target, that is, train the gun on the point to which the target will have moved during the projectile's flight. Projectile and target will arrive at this point at the same time.

A correction is made for the error introduced by the Earth's rotation only on guns larger than 5 inches, since the error is negligible in smaller guns.

RANGE TABLES

To hit a target, knowledge of the force action during the time of flight and of the resulting trajectory of the projectile is required. It is not practical to maintain a record of the trajectories that would occur under all the possible conditions encountered in the fleet. Instead, standard ballistic conditions have been arbitrarily selected. The trajectories that result from experimental firings under controlled conditions are measured and studied. During the experiment, variations from the standard conditions are introduced and their effects on the trajectories are calculated. All these factors are correlated and the results are tabulated into a usable form in the range tables. Every possible combination of gun, projectile, and initial velocity has its range table. A sample portion of a range table for a 5-inch gun with an initial velocity of 2,500 ft/s is shown in figure 5-12.

As you can see, a great deal of information is included in a range table. These tables are available as Ordnance Pamphlets (OPs). Your ship will have range tables for each size gun installed and for all possible firing circumstances.

The first eight columns of the tables describe the characteristics and the shape of a projectile's trajectory fired from a stationary gun. The figures in the columns have been determined by experimental firings of this particular combination and by higher mathematics at the Naval Weapons Laboratory.

During an experimental firing, the following conditions are assumed to exist.

1. The Earth is flat, and nonrotating.
2. The atmosphere is standard.
3. No wind is blowing.
4. The elevation angle is measured from a horizontal plane–the earth's surface.
5. The gun and target are both stationary.
6. The projectile is standard in shape and weight.
7. The initial velocity has the designed value.

Experimental firings are conducted under conditions as close as possible to those listed above. The actual trajectories are carefully measured. Obviously, some of the assumed conditions are impossible to obtain. Deviations from these conditions are taken into account in the computations on which the range tables are based.

Using the Range Table

Notice that column 1 of the range table in figure 5-12 tabulates a series of ranges in 100-yard steps. The page illustrated runs from 4500 yards to 7900 yards. The entire range table for this gun runs from 1000 yards to 23,936 yards.

Column 2 gives the angle of departure of the gun barrel for each range in degrees and minutes, while column 2a gives the same angle in minutes; for example, 2° equals 120 minutes. Column 2a is included because the dials of some guns are calibrated in minutes rather than degrees.

Suppose the target to be hit is 7100 yards away. In column 1 is a listing for 7100 yards. Opposite 7100 yards, in column 2, it is shown that an angle of departure of 4° 19.3 'is needed obtain this range. This angle of departure is set on the gun.

Column 6 of the table states that, at this range, drift is equal to 6.1 yards. This must be converted to an angular value.

Because drift is always to the right, the line of fire is offset to the left.

If all the assumed conditions are present, the trajectory will be exactly as described in the first eight columns of the table, and the target will be hit.

The chances of firing under standard conditions are, for all practical purposes, nonexistent. The remaining columns show how deviation from standard condtions affect the trajectory described in the first eight columns. This range table will be used to compute the corrections for these deviations. However, for the purpose of this discussion the gun and target will continue to be considered stationary, with no wind blowing. Before considering these factors, it would be best to have a look at the tracking, or motion problem.

Algebraic signs are given to the values in the columns to indicate the direction of the error caused by the deviation at the head of the column. If there is no sign, a positive sign is assumed. Positive signs indicate that the factor will cause (1) range to increase, (2) elevation to increase, or (3) deflection to the right, and (4) the deviation is higher than the standard. Negative signs indicate that the factor will cause (1) range to decrease, (2) elevation to decrease, or (3) deflection to the left, and (4) deviation is below the standard.

The correction necessary to compensate for an error is equal and opposite to the error.

Effect of Air Density

A STANDARD ATMOSPHERE is arbitrarily assumed. This standard assumes a temperature at sea level of 59°F, and a barometric pressure of 29.53 inches. The standard also assumes that the air density decreases, according to a standard formula, as altitude increases.

Any variation of air density from the standard will have to be corrected. The chances are that the air density, when a gun is fired, has

5-IN. 54-CAL. GUN I.V. 2500 F.S. 70-POUND PROJECTILES

RANGE	ANGLE OF ELEVATION			CHANGE IN ANGLE OF ELEVATION FOR 100 YDS. INCREASE IN RANGE	ANGLE OF FALL		TIME OF FLIGHT	STRIKING VELOCITY	DRIFT	DANGER SPACE FOR A TARGET 20 FT. HIGH	MAXIMUM ORDINATE
1	2		2A	2B	3		4	5	6	7	8
YARDS	DEG.	MIN.	MINUTES	MINUTES	DEG.	MIN.	SECONDS	FT./SEC.	YARDS	YARDS	FEET
4500	2	24.6	144.6	3.9	2	55	6.22	1884	2.0	136	156
4600	2	28.5	148.5	3.9	3	0	6.38	1871	2.1	132	164
4700	2	32.4	152.4	4.0	3	6	6.55	1858	2.2	127	172
4800	2	36.4	156.4	4.0	3	11	6.71	1846	2.3	123	181
4900	2	40.4	160.4	4.1	3	17	6.87	1833	2.4	120	190
5000	2	44.5	164.5	4.0	3	23	7.04	1821	2.6	116	199
5100	2	48.5	168.5	4.2	3	29	7.20	1808	2.7	112	209
5200	2	52.7	172.7	4.1	3	35	7.37	1796	2.8	109	218
5300	2	56.8	176.8	4.3	3	41	7.54	1783	2.9	106	228
5400	3	1.1	181.1	4.2	3	48	7.71	1771	3.1	103	239
5500	3	5.3	185.3	4.3	3	54	7.88	1759	3.2	100	250
5600	3	9.6	189.6	4.3	4	1	8.05	1747	3.4	97	261
5700	3	13.9	193.9	4.4	4	7	8.22	1735	3.5	94	272
5800	3	18.3	198.3	4.4	4	14	8.40	1723	3.7	92	284
5900	3	22.7	202.7	4.5	4	21	8.57	1711	3.8	89	296
6000	3	27.2	207.2	4.5	4	28	8.75	1699	4.0	87	308
6100	3	31.7	211.7	4.5	4	35	8.93	1687	4.1	85	321
6200	3	36.2	216.2	4.6	4	42	9.11	1675	4.3	82	334
6300	3	40.8	220.8	4.7	4	50	9.29	1663	4.5	80	347
6400	3	45.5	225.5	4.7	4	57	9.47	1652	4.7	78	361
6500	3	50.2	230.2	4.7	5	5	9.65	1640	4.9	76	375
6600	3	54.9	234.9	4.8	5	12	9.84	1628	5.1	74	389
6700	3	59.7	239.7	4.8	5	20	10.02	1617	5.3	72	404
6800	4	4.5	244.5	4.9	5	28	10.21	1605	5.5	71	419
6900	4	9.4	249.4	4.9	5	36	10.40	1594	5.7	69	435
7000	4	14.3	254.3	5.0	5	45	10.59	1583	5.9	67	451
7100	4	19.3	259.3	5.0	5	53	10.78	1571	6.1	65	468
7200	4	24.3	264.3	5.1	6	2	10.97	1560	6.3	64	485
7300	4	29.4	269.4	5.1	6	10	11.17	1549	6.6	62	502
7400	4	34.5	274.5	5.2	6	19	11.36	1538	6.8	61	520
7500	4	39.7	279.7	5.2	6	28	11.56	1527	7.0	59	538
7600	4	44.9	284.9	5.3	6	37	11.76	1516	7.3	58	557
7700	4	50.2	290.2	5.4	6	47	11.96	1505	7.6	57	576
7800	4	55.6	295.6	5.4	6	56	12.16	1494	7.8	55	595
7900	5	1.0	301.0	5.4	7	6	12.37	1483	8.1	54	616

166.199

Figure 5-12.—Range table for 5-inch gun.

5-IN. 54-CAL. GUN I.V. 2500 F.S. 70-POUND PROJECTILES

RANGE	CHANGE IN RANGE FOR							DEFLECTION FOR			CHANGE IN HEIGHT OF IMPACT FOR 100 YARDS CHANGE IN RANGE
	10 F.S. INCREASE IN INITIAL VELOCITY	1 LB. DECREASE IN PROJECTILE WEIGHT	10 PCT. DECREASE IN AIR DENSITY	10 DEG. F. DECREASE IN AIR TEMPERATURE	10 KNOT MOTION IN PLANE OF FIRE			10-KNOT MOTION PERPENDICULAR TO PLANE OF FIRE			
					WIND	GUN	TARGET	WIND	GUN	TARGET	
1 YARDS	10 YARDS	11 YARDS	12 YARDS	12A YARDS	13 YARDS	14 YARDS	15 YARDS	16 YARDS	17 YARDS	18 YARDS	19 FEET
4500	32	23	78	5	7	28	35	4.6	30.4	35.0	15
4600	32	23	81	5	7	29	36	4.8	31.1	35.9	16
4700	33	23	85	5	7	30	37	5.1	31.8	36.9	16
4800	34	23	88	5	8	30	38	5.3	32.5	37.8	17
4900	34	23	92	5	8	31	39	5.5	33.1	38.7	17
5000	35	23	96	6	8	31	40	5.8	33.8	39.6	18
5100	35	24	99	6	9	32	41	6.1	34.5	40.6	18
5200	36	24	103	6	9	32	41	6.3	35.2	41.5	19
5300	36	24	107	6	9	33	42	6.6	35.9	42.4	19
5400	37	24	111	6	10	34	43	6.9	36.5	43.4	20
5500	38	24	115	7	10	34	44	7.1	37.2	44.4	20
5600	38	24	119	7	11	35	45	7.4	37.9	45.3	21
5700	39	24	124	7	11	35	46	7.7	38.6	46.3	22
5800	39	24	128	7	12	36	47	8.0	39.2	47.3	22
5900	40	24	132	8	12	36	48	8.3	39.9	48.3	23
6000	40	24	137	8	12	37	49	8.6	40.6	49.3	23
6100	41	24	141	8	13	37	50	9.0	41.3	50.3	24
6200	41	24	146	8	13	38	51	9.3	42.0	51.3	25
6300	42	23	151	9	14	39	52	9.6	42.6	52.3	25
6400	43	23	155	9	14	39	53	10.0	43.3	53.3	26
6500	43	23	160	9	15	40	54	10.3	44.0	54.3	27
6600	44	23	165	9	15	40	55	10.7	44.7	55.4	27
6700	44	23	170	10	16	41	56	11.1	45.4	56.4	28
6800	45	23	175	10	16	41	57	11.4	46.1	57.5	29
6900	45	23	180	10	17	42	59	11.8	46.7	58.5	29
7000	46	22	185	11	17	42	60	12.2	47.4	59.6	30
7100	46	22	190	11	18	43	61	12.6	48.1	60.7	31
7200	47	22	196	11	18	43	62	13.0	48.8	61.8	32
7300	47	22	201	11	19	44	63	13.4	49.5	62.9	32
7400	48	22	206	12	20	44	64	13.8	50.2	64.0	33
7500	48	21	212	12	20	45	65	14.3	50.8	65.1	34
7600	49	21	217	12	21	45	66	14.7	51.5	66.2	35
7700	49	21	223	13	21	46	67	15.1	52.2	67.3	36
7800	50	20	229	13	22	46	68	15.6	52.9	68.5	36
7900	50	20	234	13	23	47	70	16.0	53.6	69.6	37

166.199

Figure 5-12.—Range table for 5-inch gun—Continued.

some value other than standard. A value of air density is obtained by the ship's aerologist and furnished to the weapons department in the form of a PERCENTAGE VARIATION from the standard density. The air density varies with different altitudes, and the effect of the density depends on whether the firing is at long or short range. At long range most of the trajectory is in the thin upper air. This requires the use of an average value, called BALLISTIC DENSITY, for that range.

Now, look at column 12 of the range table. It shows the error which will be produced if the average air density is 10 percent less than standard density. If the density is less, the resistance to the movement of the projectile will be less, and the projectile will go farther. In column 12, opposite 7100 yards in the range column, is the value 190, which means that, if an angle of departure of 4° 19.3′ is set into the gun and air density is 10 percent below standard, the target will be overshot by 190 yards.

Now, suppose the density were only 5 percent low. Then, the error would be 5/10 of 190 yards, or an error of approximately 95 yards. Since it is necessary to reshoot, this 95 yard error will be subtracted from the original range of 7100 yards. This leaves 7005 yards. Refer to column 2 of the range table for 7000 yards. The new angle of departure is 4° 14.3′.

If there is no aerologist aboard to give a value of ballistic density, an approximate air density correction can be worked out by means of a graphic device called a nomogram. An air density nomogram is included in most range tables (fig. 5-13).

Using the Air Density Nomogram

When ballistic air density is not available, figure 5-13 should be used to determine the change in range due to variation of air density from standard. Figure 5-13 is applicable when either air density at the surface or barometric pressure and air temperature at the surface are known. When air density at the surface is known:

Align (D) and (R) to get change in range

When barometric pressure and air temperature at the surface are known:

Align (B) and (T) to get point on (D)
Align (D) and (R) to get change in range

EXAMPLES:

1. Given:	Air density (surface) . .	102 %
	Range	9000 yd
Result:	Change in range	-60 yd
2. Given:	Barometer	28.0 in
	Temperature	60 °F
	Range	9000 yd
Result:	Change in range	+160 yd

Changes in Initial Velocity

The range table is based on a U (initial velocity, formerly symbolized as iv), of 2500 ft/s. This is the initial velocity that the gun is designed to have. However, few guns in the fleet actually develop their designed velocities. There are two reasons for the lower initial velocities obtained in actual firing.

One reason is the wear of the gun barrel. Every time the gun is fired the inside of the barrel is slightly worn away, so that the bore becomes enlarged. This reduces the pressure behind the projectile and lowers the initial velocity.

Records are kept of the number of times a gun is fired. In this record a round of target ammunition using a reduced powder charge is counted as an equivalent fraction of a service round. The total of service rounds plus target rounds counted in this way is called EQUIVALENT SERVICE ROUNDS. Curves have been worked out experimentally for each type of naval gun, showing the U loss to be expected after any number of equivalent service rounds fired.

The same thing may be accomplished by measuring the enlargement of the bore with a STAR GAGE or an EROSION GAGE. (For

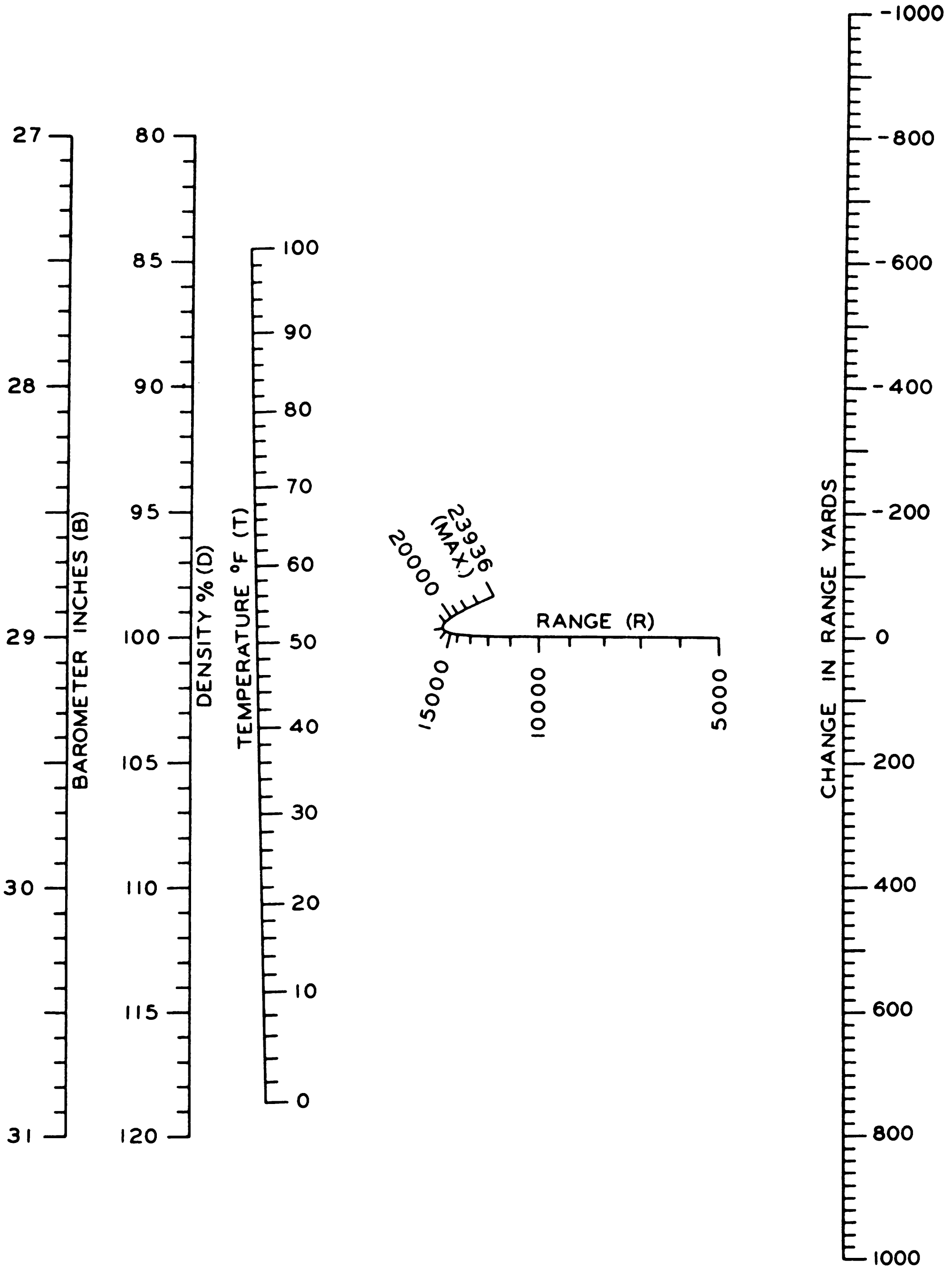


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Figure 5-13.—Change in range for variation in density of air.

information on star and erosion gages, see *Gunner's Mate G 1 & C,* NAVEDTRA 10186, the latest edition.) Curves are available showing the U loss for any amount of enlargement. For example, if the bore of a 5-inch gun is enlarged 0.04 inches, the U will be reduced about 28 ft/s. This is more accurate than counting the rounds fired. The usual procedure is to star-gage guns periodically to get a value of U loss, and then keep track of rounds fired between star gagings.

The second reason for lower initial velocity is the change in the condition of the powder. With modern manufacturing methods, the chemical composition of smokeless powder does not vary to any great extent, but powder has a different amount of strength at different temperatures. The warmer the powder, the more powerful it is.

Naval guns are designed to obtain standard U when the powder has a temperature of 90°F. Every degree of variation from this standard temperature will change the 5-inch gun U by approximately 2 ft/s. For instance, if the powder being used has a temperature of 80°F, you know that the U will be 20 ft/s less than the rated value. Since magazine temperatures are normally below standard, this factor will usually reduce U. And since powder temperature changes slowly, the average magazine temperature for the past several days should be used.

Combining these factors, erosion and powder temperature, will result in a figure for the total change in U from the standard conditions.

Column 10 of the range table gives the change in range for an increase of 10 ft/s in U. Suppose the figures on gun erosion and powder temperature indicate a U loss of 38 ft/s. The range is still 7100 yards. Found in column 10, opposite this range, is a value of 46 yards. To find the effect on the range with a 38 ft/s U loss, multiply 46 times 38/10. The result is 175 yards. This means that, using the angle of departure given by the range table for 7100 yard range, the target will be undershot by 175 yards. Obviously, if you are falling short, the thing to do is to increase range.

Projectile Weight

Another assumption that was made in computing the range table was that the weight and shape of the projectile were standard. However, in case it should be necessary to fire a projectile of nonstandard weight, column 11 of the range table gives the change in range to be expected if the projectile is reduced in weight by one pound.

Finding Gun Range

So far each of the errors in range has been considered separately, but in practice, all errors will be combined. Thus, in the previous examples, the variation in air density was causing an error of 95 yards over, while the variation in U was causing an error of 175 yards short. The combined effect is an error of 80 yards short, or about 100 yards short. A short error requires an odd correction. So, find the angle of departure corresponding to a range of 7100 plus 100, or 7200 yards.

The way the correction is applied is important, since the correction will be equal in amount but opposite in sign to the error. In other words, a SHORT ERROR requires an ADD CORRECTION, while a LONG ERROR requires a DROP CORRECTION. The total correction is called the GUN BALLISTIC IN RANGE.

BALLISTICS IN THE FIRE CONTROL SYSTEM

Using a range table to solve the ballistic problem is time consuming. And there is little time when the shooting starts. From this study of ballistics, you know that to hit a target, these problems must be solved. Normally it is the job of the fire control computer to solve the ballistic problem. The projectile's initial velocity, however, is calculated before the shoot, and is an input to the computer.

The range tables are built into the computer. For example, in a mechanical computer ballistic cams are used to solve the problem (fig. 5-14). These cams are cut so that if the input shaft is rotated by an amount proportional to the range, the cam follower will move an amount proportional to one of the columns of the range table—angle of departure, time of flight, striking velocity, etc.

The postfiring evaluation of a practice shot depends on the range tables. In the evaluation, the range table information is used as the criterion to judge the accuracy of the shot. The location of the projectile's impact point, as observed by spotters, and the point at which the

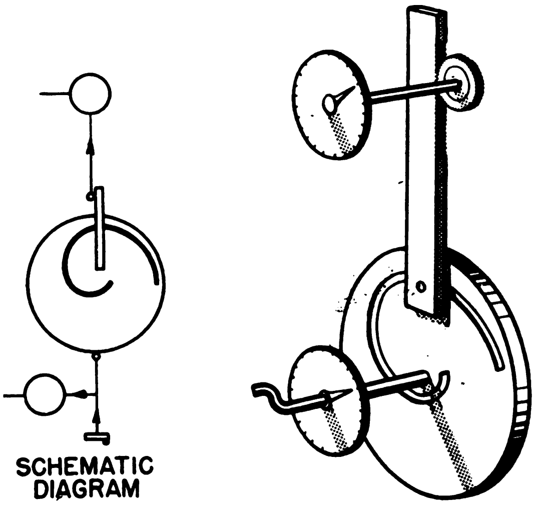

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Figure 5-14.—A simple ballistic cam.

fire control system computed it should have landed are compared with the solution calculated from range table data. In this way the performance of a gun battery against proven standards can be judged.

COMPUTATION OF INITIAL VELOCITY

As mentioned earlier, the projectile's initial velocity (iv) is calculated before a gun shoot, and is an input to the fire control computer. The iv is determined by variables such as air and powder temperature, expected firing range, and gun bore wear. All are constantly changing. Therefore, you should calculate iv before every scheduled gunnery exercise.

The calculation of iv is accomplished with the aid of an iv form such as the one shown in figure 5-15. There may be minor deviations in the calculation of iv from ship to ship because of the type of computer receiving this information. Your LPO will explain any differences.

Preliminary Data

Prior to performing the actual computation for iv, the correct data must be entered in section A of the form shown in figure 5-15. This data makes it possible to perform the necessary work without having to refer back and forth from the worksheet to the range table.

In item A-1, enter the powder temperature taken from the magazine or ready service stowage where the powder to be used is stored. The powder temperature should be an average of a minimum of three days temperature readings.

In item A-2, enter the powder index number taken from the powder container. It is best to use powder with the same index for an entire exercise so that initial velocity computations will not vary.

Item A-3 is not normally completed for the 5-inch rapid-fire gun, but may be required for slow-fire guns.

Item A-4, like item A-3, is not normally used in initial velocity computations for rapid-fire guns, but may be required for slow-fire guns.

In item A-5, enter the last erosion gage readings. Erosion gage readings are normally taken by ship's force personnel every 3 months or every 50 rounds fired, as prescribed in the applicable maintenance requirement cards.

In item A-6, enter the temperature, in degrees fahrenheit, from the dry bulb thermometer normally located on the ship's bridge.

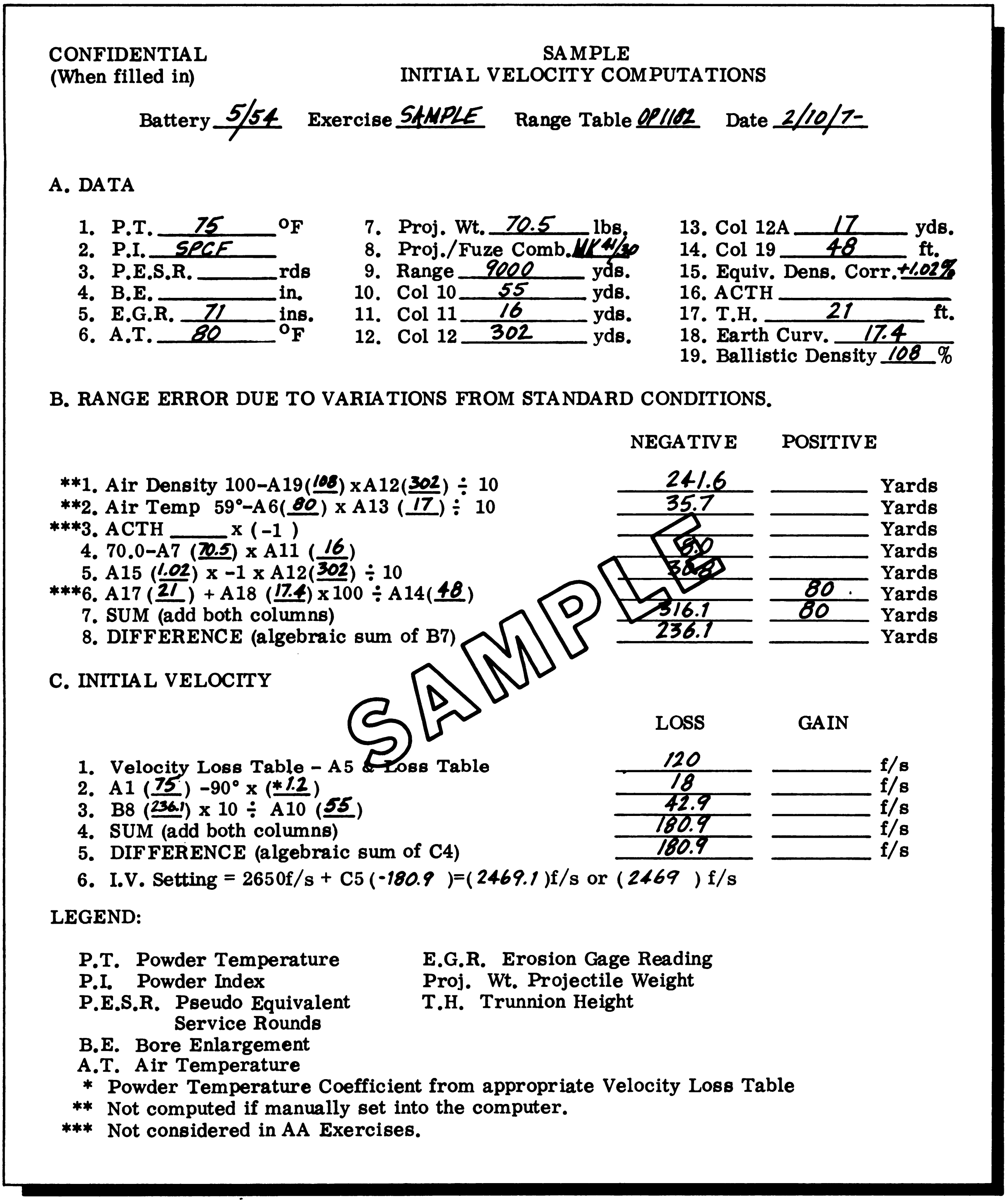
In item A-7, enter the weight, in pounds, of the projectile type that is to be fired. The weight is stenciled on the projectile.

In item A-8, enter the mark (Mk) of both the projectile to be fired and its fuze. This information is stenciled on the projectile.

In item A-9, enter the best estimate of the expected firing range. Complete items A-10 through A-14 using the applicable range table and the estimated range in item A-9.

In item A-15, enter the density correction from the range table, which is based on the projectile/fuze combination obtained for item A-8. If the projectile/fuze combination does not appear in the range table OP, this item is considered to be zero.

In item A-16, enter the arbitrary correction to hit (ACTH). This entry is obtained from conducting a long range calibration firing, and it corrects for unaccountable errors. This entry is required only when firing surface exercises.



CONFIDENTIAL
(When filled in)

SAMPLE
INITIAL VELOCITY COMPUTATIONS

Battery 5/54 Exercise SAMPLE Range Table OP1102 Date 2/10/7-

A. DATA

1. P.T. 75 °F
2. P.I. SPCF
3. P.E.S.R. ______ rds
4. B.E. ______ in.
5. E.G.R. 71 ins.
6. A.T. 80 °F
7. Proj. Wt. 70.5 lbs.
8. Proj./Fuze Comb. MK 41/30
9. Range 9000 yds.
10. Col 10 55 yds.
11. Col 11 16 yds.
12. Col 12 302 yds.
13. Col 12A 17 yds.
14. Col 19 48 ft.
15. Equiv. Dens. Corr. +1.02%
16. ACTH ______
17. T.H. 21 ft.
18. Earth Curv. 17.4
19. Ballistic Density 108 %

B. RANGE ERROR DUE TO VARIATIONS FROM STANDARD CONDITIONS.

	NEGATIVE	POSITIVE	
**1. Air Density 100-A19(108) xA12(302) ÷ 10	241.6		Yards
**2. Air Temp 59°-A6(80) x A13 (17) ÷ 10	35.7		Yards
***3. ACTH ____ x (-1)			Yards
4. 70.0-A7 (70.5) x A11 (16)	8.0		Yards
5. A15 (1.02) x -1 x A12(302) ÷ 10	30.8		Yards
***6. A17 (21) + A18 (17.4) x 100 ÷ A14(48)		80	Yards
7. SUM (add both columns)	316.1	80	Yards
8. DIFFERENCE (algebraic sum of B7)	236.1		Yards

C. INITIAL VELOCITY

	LOSS	GAIN	
1. Velocity Loss Table - A5 & Loss Table	120		f/s
2. A1 (75) -90° x (*1.2)	18		f/s
3. B8 (236.1) x 10 ÷ A10 (55)	42.9		f/s
4. SUM (add both columns)	180.9		f/s
5. DIFFERENCE (algebraic sum of C4)	180.9		f/s

6. I.V. Setting = 2650f/s + C5 (-180.9)=(2469.1)f/s or (2469) f/s

LEGEND:

P.T. Powder Temperature
P.I. Powder Index
P.E.S.R. Pseudo Equivalent Service Rounds
B.E. Bore Enlargement
A.T. Air Temperature
E.G.R. Erosion Gage Reading
Proj. Wt. Projectile Weight
T.H. Trunnion Height

* Powder Temperature Coefficient from appropriate Velocity Loss Table
** Not computed if manually set into the computer.
*** Not considered in AA Exercises.

170.180

Figure 5-15.—I.V. Form.

In item A-17, enter the average trunnion height for all firing guns measured from the waterline. The information for this entry is obtained from the ship's blueprints. This entry is required only when firing surface exercises.

In item A-18, enter the correction obtained from an earth curvature table for the range entered in item A-9. This entry is required only when firing surface exercises.

In item A-19, enter the ballistic density correction obtained by message from the applicable naval weather service command.

Range Error

The B portion of the initial velocity computation form relates to the range error due to variations from the standard conditions. In other words, it is the difference between the expected impact point for standard conditions and the expected impact point for existing conditions. The terms "negative" and "positive" in figure 5-15, may be replaced by "short" and "over", respectively, on other forms. The formula for each entry is given on the form.

Item B-1 is the range error in yards for variation in the density of the air, based on the Navy standard which is 100 percent. The values needed for this entry are contained in A-19 (ballistic density) and A-12 (range error for a 10 percent decrease in air density at the firing range).

Item B-2 is the change in range due to variations in air temperature from the standard (with 59°F as the standard). The formula given in figure 5-15 includes the air temperature from item A-6 and the entry in item A-13 (taken from column 12A of the range table). If the air temperature is above standard, the entry is made in the negative (short) column; if below standard, the entry is made in the positive (over) column.

Item B-3 is the ACTH range error entry from item A-16 multiplied by -1, to change the entry's sign to a minus. This entry is omitted when firing at an air target or when the surface ACTH is negligible.

Item B-4 is the range correction for variations in projectile weight from the standard. The range table is set up for a projectile weight of 70 pounds, and the projectile in the example weighs 70.5 pounds (item A-7). In the formula given, actual weight (A-7) is subtracted from the range table weight, and the result is then multiplied by the entry in item A-11 (column 11 of the range table). Thus,

$$(70.0 - 70.5)16 =$$
$$-.5 \times 16 = -8$$

Column 11 gives the effect on range due to a decrease of 1 pound in projectile weight. Since in the example the projectile is heavier than standard, it will leave the gun at a lower initial velocity, which results in a decrease in range.

Item B-5 solves for the change in range caused by the density effect when firing a projectile/fuze combination other than that for which the range table was constructed (VT). The formula given in figure 5-15 includes the equivalent density correction (item A-15) and the entry in item 12 (column 12 of the range table). The sign of the formula result determines the correct entry column. Column 12 of the range table gives the effect on range due to a 10-percent decrease in air density. This decrease has the effect of making the atmosphere thinner, therefore range is always increased. Due to the -1 constant in the formula, it appears as a decrease in range.

Item B-6 is the trunnion height and Earth curvature range error entry. The formula for this entry includes Earth curvature (A-18), trunnion height (A-17), and A-14 which was obtained from column 19 of the range table.

In item B-7, enter the sum of the negative (short) and positive (long) columns, separately.

In item B-8, the total range error due to variations from standard conditions is entered. This entry is arrived at by subtracting the smaller sum in item B-6 from the larger sum (algebraically) and entering the answer in the column under the larger number.

Initial Velocity

This computation will determine the initial velocity loss or gain that will be used in the fire control computer.

Item C-1 is the entry for the velocity loss due to erosion of the gun barrel. As explained earlier, it is recommended that bore erosion gage readings be used for this entry for a rapid-fire gun. First locate the U.S. Naval Weapons Laboratory's velocity loss versus erosion gage table in the range table in OP 1182 (fig. 5-16). Two tables are provided in the OP; one for a powder index of SPCF and the other for a powder index of SPD. Since the entry in A-2 calls for SPCF, that table is used. Assuming that no rounds have been fired since the last erosion gage readings were taken, an EGR of 71 inches (item A-5) will produce a velocity loss of 120 ft/s. The entry (C-1) is made in the loss column as a -120 ft/s. Since this is a loss table, any positive number is a loss and any negative number is a gain.

Item C-2 is the velocity loss entry for variations in the powder temperature from the standard (90°F). The example C-2 in figure 5-15 shows the entry in A-1, 75°, being subtracted from 90°. The result, 15°, is multiplied by the powder temperature coefficient (1.2), which produces a velocity loss of 18 ft/s. The powder temperature coefficient value is found in the velocity loss table of the range table OP. If the powder temperature is below standard, the entry is entered in the loss column, and if above standard, is entered in the gain column.

Item C-3 is the velocity loss or gain entry due to the range error. It was computed in item B-8. In the example provided, the range error found in item B-8 (236.1 yards) is multiplied by 10 and the result divided by the entry in item A-10 (55 yards), producing a velocity loss of 42.9 ft/s.

Item C-4 is the sum of the loss column and yards gain column, listed separately.

Item C-5 is the entry for the total initial velocity correction due to variations from standard conditions. It is arrived at by subtracting the smaller sum in C-4 from the larger sum, and entering the answer in the column under the larger number.

Item C-6 is used to find the initial velocity quantity that will be set into the fire control computer. The nominal velocity of a 5-inch gun is 2650 ft/s. The initial velocity setting is found by algebraically adding the total initial velocity correction (item C-5) to the nominal velocity. The answer is the quantity set into the computer.

FIRE CONTROL PROBLEM PREREQUISITES

Fire control is the technique of delivering effective fire so as to damage or destroy a selected target. The fire control problem is solved by the fire control computer. Although the steps in the solution of the problem of hitting a moving target from a moving ship are many, they can be summarized in the following manner.

1. Determine present target position in relation to ownship.
2. Predict future target position, in relation to the time of flight of the projectile.
3. Calculate the required corrections to the line of fire of the gun barrel, caused by gravity, drift, and wind effects on the projectile.
4. Stabilize the various units in the fire control system with the gyro (stable element).
5. Transmit the firing data to the gun mount.

You will study these steps of the solution in detail later in this chapter. As an aid to understanding the problem, we will first cover the mathematics that are involved, the symbols used to denote the fire control quantities, and the various factors which affect the problem.

To solve any mathematical problem, there must be certain known quantities or references in order to find the unknown quantity. This is also true with the fire control computer. References are needed from which quantities can be measured. This section will provide information on these basic quantities, which are used as references to solve the fire control problem.

VELOCITY LOSS VS EROSION GAUGE (MARK 2 MOD 0) READING DATA (TENTATIVE)

5"/54 Caliber Guns, MARK 18 MODS 1 and 3 and MARK 19 MOD 0
Worn with SPCF Powder

Projectile Weight: 70 lbs.
Propellant Charge: Full

Nominal Velocity: 2650 f/s
Propellant Index: SPCF

Erosion Gauge Reading	0	1	2	3	4	5	6	7	8	9
47	-2	-1	-1	0	0	1	2	2	3	3
48	4	4	5	5	6	6	7	7	8	8
49	9	9	10	10	11	11	12	12	13	13
50	14	14	15	15	16	16	17	17	18	18
51	19	19	20	20	21	21	22	22	23	23
52	24	24	25	25	26	26	27	27	28	28
53	29	29	30	30	31	31	32	32	33	33
54	34	34	35	35	36	36	37	37	38	38
55	39	39	40	40	41	41	42	42	43	43
56	44	44	45	45	46	46	47	47	48	48
57	49	49	50	50	51	51	52	52	53	53
58	54	54	55	55	56	56	57	57	58	59
59	59	60	60	61	61	62	62	63	63	64
60	64	65	65	66	66	67	67	68	68	69
61	69	70	70	71	71	72	72	73	73	74
62	74	75	75	76	76	77	77	78	78	79
63	79	80	80	81	81	82	83	83	84	84
64	85	85	86	86	87	87	88	88	89	89
65	90	90	91	91	92	92	93	93	94	94
66	95	95	96	96	97	97	98	98	99	99
67	100	100	101	101	102	102	103	103	104	104
68	105	105	106	106	107	107	108	108	109	109
69	110	110	111	111	112	112	113	113	114	114
70	115	115	116	116	117	117	118	118	119	119
71	120	120	121	121	122	122	123	123	124	124
72	125	125	126	126	127	127	128	128	129	129
73	130	130	131	131	132	132	133	133	134	134
74	135	135	136	136	137	137	138	138	139	139
75	140	140	141	141	142	142	143	143	144	144
76	145	145	146	146	147	147	148	148	149	149
77	150	150	151	151	152	152	153	153	154	154
78	155	155	156	156	157	157	158	158	159	159
79	160	161	161	162	162	163	163	164	164	165
80	165	166	166	167	168	168	169	169	170	170
81	171	171	172	172	173	173	174	174	175	175
82	176	176	177	177	178	178	179	179	180	180
83	181	181	182	182	183	183	184	184	185	185
84	186	186	187	187	188	188	189	189	190	190

Powder Temperature Coefficient: 1.2 f/s per °F

E. S. R. Factor: 0.33

U. S. Naval Weapons Laboratory
Dahlgren, Virginia
June, 1970

166.201

Figure 5-16.—Velocity loss vs erosion gauge (Mark 2 Mod 0) reading data (tentative).

FRAMES OF REFERENCE

A frame of reference (fig. 5-17) is a system of lines, angles, and planes within which target position can be measured and the lead angles computed. A position can be described only by relating it to a known reference point, for position is a relative quantity. A location is described by measuring its direction and distance from a known point. Try to describe any location, say the director or the plotting room, without a reference point from which to start the description. A reference frame has a point, called the point of origin or reference point, from which all measurements are made.

The fire control problem consists mainly of measuring and predicting motions and forces acting during the time of flight of the projectile. Motions and forces can be described by vectors. A vector represents both the direction and the magnitude of a quantity. The problem's solution deals with the plotting, resolution, addition, and subtraction of vectors. A frame of reference is established within which the vectors can be plotted.

There are two frames of reference used in GFCSs. One frame is considered rigidly attached to ownship, while the other frame is considered rigidly attached to the surface of the Earth. A GFCS may use either frame or a combination of the two. The frame being used can be recognized by the reference point's location and how it was established.

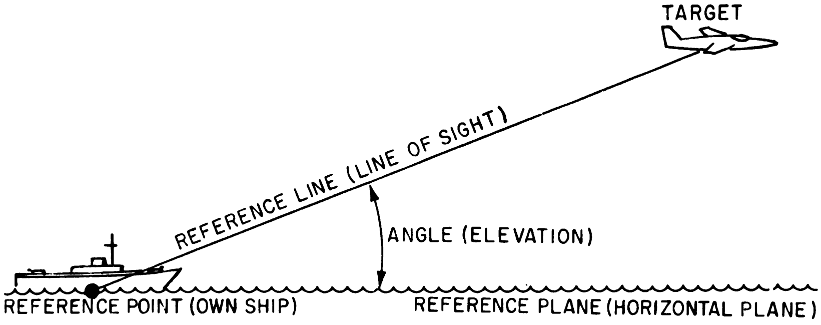
The frame of reference rigidly attached to ownship has a reference point which is built into the fire control system. All measurements are made from this reference point, which is located in the ship's deck plane. Since the deck plane moves in all directions with ownship, as shown in figure 4-3, the FCSs using this frame are unstabilized.

The Earth frame of reference is considered attached to the surface of the Earth and rotates with it. The reference point is located in the horizontal plane, which is independent of the ship's roll and pitch motions. Hence this frame is stabilized. The horizontal plane is established by the stable element, again shown in figure 4-3.

In an FCS that is fully stabilized, measurements are made with respect to the horizontal and vertical planes. This is an ideal reference frame, since the target is independent of ownship's roll and pitch. However, in most GFCSs only sections of the system are stabilized. The stabilized section, normally the computer, uses the Earth reference frame and measures target position with respect to the horizontal and vertical planes. In the unstabilized sections the reference point is located in the deck plane and measures target position with respect to the deck and the normal planes.

BASIC LINES, ANGLES, AND PLANES

To introduce the basic lines, angles, and planes in an orderly manner we will start with a


TARGET
REFERENCE LINE (LINE OF SIGHT)
ANGLE (ELEVATION)
REFERENCE POINT (OWN SHIP)
REFERENCE PLANE (HORIZONTAL PLANE)

166.202

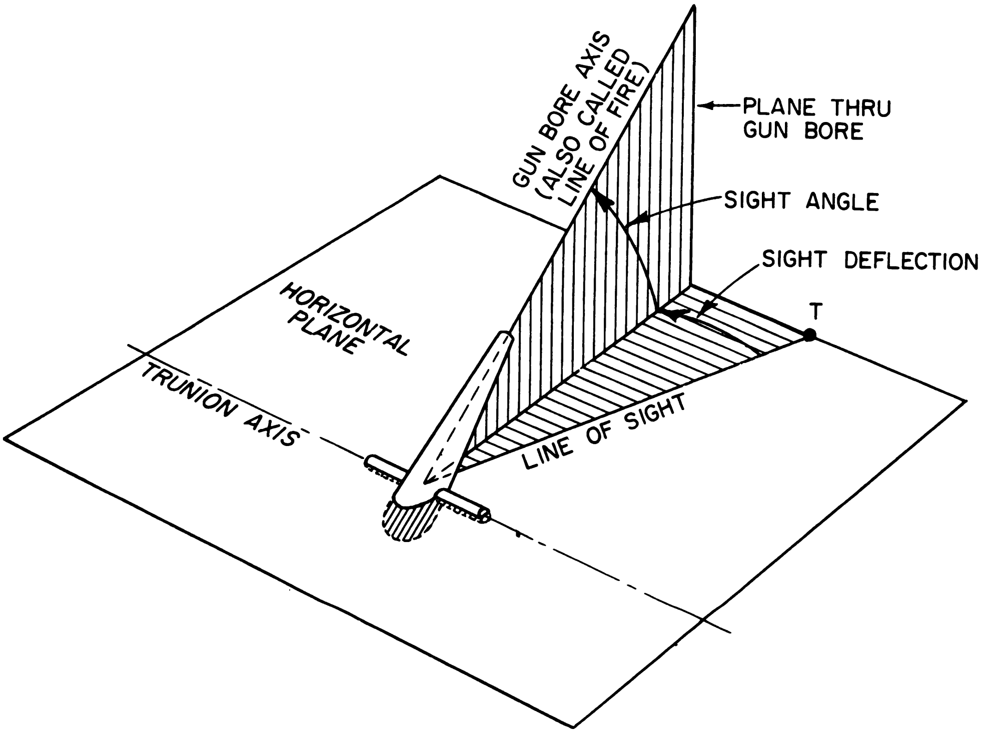
Figure 5-17.—Frame of reference.

simple situation, that of trying to hit a stationary surface target from a stationary gun. Consider the exterior ballistics. From the previous discussion of this subject, two important facts are apparent. First, the projectile takes a definite period of time–called the time of flight–to travel to the target. The second ballistic fact is that the projectile's trajectory is curved. The curvature is due to gravity and air resistance, which are always present. Consequently, these two facts are always present.

Although the ballistic portion of the fire control problem concerns many quantities, the time of flight and the trajectory's curvature are the ultimate facts which must be considered if the target is to be hit. From this, it can be concluded that two basic lines are necessary. One line, called the line of sight (los), is used to establish the present position of the target; the second line, called the line of fire (lof), is used to establish the position of the gun bore with respect to the los (fig. 5-18).

Until now the target has not been located with respect to the gun. It was assumed that the gun was on the target to begin with, and the gun bore was simply offset for the ballistic corrections. To proceed further in this discussion the position of the target must be established in the coordinates in which the gun bore is positioned. The gun can move in train in the plane containing the axis of the gun trunnions. It can move in elevation about the trunnions, in a plane perpendicular to that in which the gun trains.

The horizontal plane (fig. 5-18) is an imaginary plane tangent to the Earth's surface at the gun. It is assumed that the gun's trunnion and the target are in the horizontal plane. It is also assumed that the Earth's surface is flat and in the horizontal plane. Corrections are made to



12.11

Figure 5-18.—Lead angles in a surface problem.

compensate for errors which will result if these assumptions are not true. These corrections will be discussed later.

Line of Sight (los)

The los is a straight line which describes the position of the target with respect to ownship (the gun). It forms a connecting link between the two, and by keeping the line on target its position is known at all times. Hence the los is the primary reference line from which the offsets are made to establish the lof. Whether the target is hit or missed is determined largely by how accurately the los is established.

Line of Fire (lof)

Figure 5-18 contains another line that needs defining. This is the line along which the gun must be pointed in order to hit the target. A more formal definition would be that it is the projection of the axis of the bore of the gun on the horizontal plane through the trunnions. The lof is established by two lead angles. One is sight angle and the other is sight deflection.

Sight Angle

In this definition, the deck plane is assumed to be in the horizontal plane, and reference is made to sight angle as it is set into a gun sight. Sight angle is the angle between the gun bore axis (lof) and the line of sight. The angle is measured in a plane perpendicular to the trunnion axis. The plane passes through the gun bore. If the gun and target are in the horizontal plane, sight angle will be set in above the horizontal plane (fig. 5-18).

Sight Deflection

In figure 5-18 notice that the line of sight although lying in the horizontal plane through the trunnion axis, is NOT perpendicular to the gun trunnions. Sight deflection is the angle by which the plane through the gun bore is deflected from the line of sight. The angle is measured in the horizontal plane through the trunnion axis which contains the line of sight.

Reference Planes

Reference planes are flat surfaces which may extend in all directions to infinity. Normally these planes are pictured with boundaries equal to the range of the fire control problem, as shown by the horizontal, vertical, and slant planes in figure 5-19. Target position and movement can be measured from these reference planes.

The most common and frequently used reference planes (fig. 5-20) are:

Horizontal Plane—The plane tangent to the Earth's surface at the location of the ship

Deck Plane—The plane coincident with or parallel to the ship's deck

Vertical Plane—A plane perpendicular to the horizontal plane and intersecting it at any designated point

Normal Plane—A plane perpendicular to the deck plane and intersecting it at any designated point

Slant Plane—A plane which intersects either the horizontal or deck plane at some discrete angle whose value is determined by the elevation angle of the line of sight

Coordinate Systems

The target's position is located in a frame of reference by a coordinate system. The coordinate system measures the target's distance and direction from the reference point. A coordinate system gives a graphic representation of the target's position.

A coordinate may be defined here as a number representing the length of a line that has a known direction relative to a reference axis. To locate a point in a plane requires two coordinates. Each coordinate represents a dimension. As an example, ownship's location can be determined by the coordinates of latitude and longitude.

It would follow then that a surface target's location from ownship can be determined by two dimensions, since both are in the same plane.

There are two basic coordinate systems (fig. 5-21) used to locate a point in a plane: (1) the rectangular coordinate system, which uses two

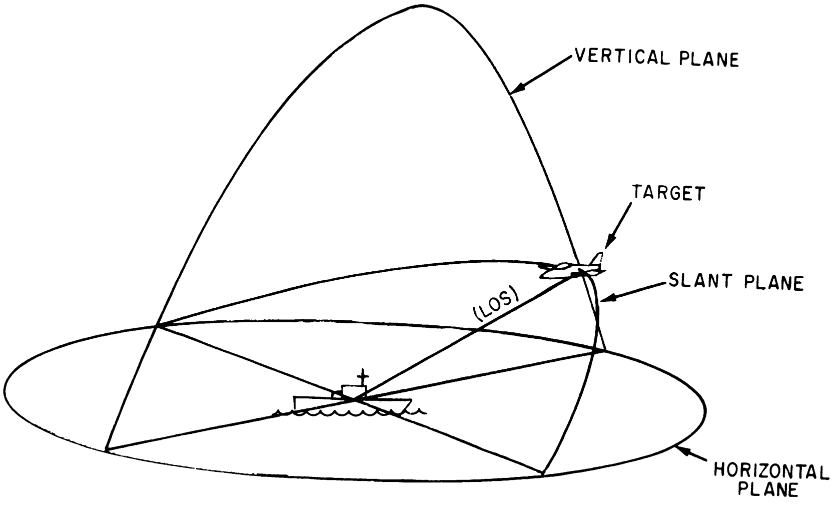


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Figure 5-19.—Reference planes.

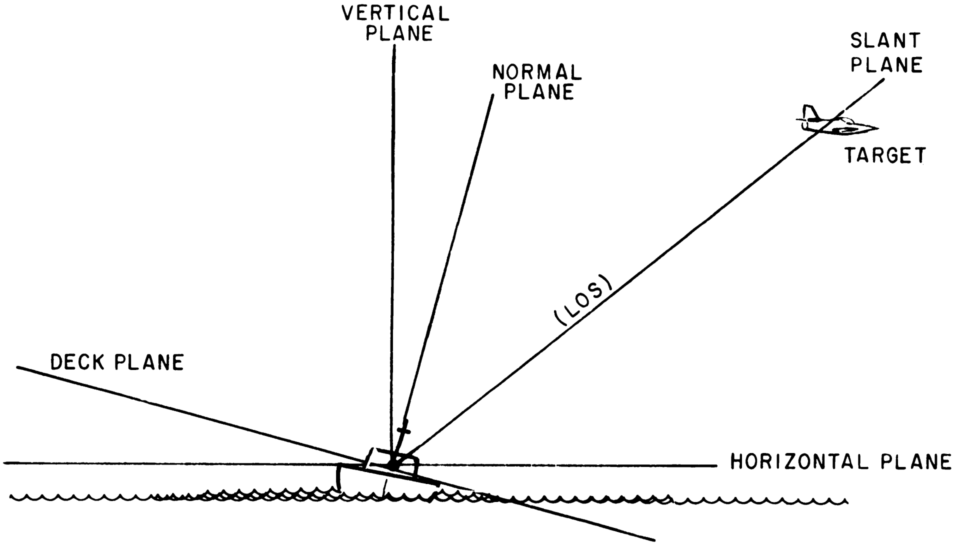

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Figure 5-20.—Reference planes.

linear coordinates; and (2) the polar coordinate system which uses one angular and one linear coordinate.

THREE DIMENSIONAL COORDINATE SYSTEM.—Until now it has been assumed the target would be in the same plane as ownship. If a target is not on the surface of the Earth, three dimensions are required to describe its position.

To locate a point not in the reference plane, the point's deviation from the reference plane must be described. The deviation is its height

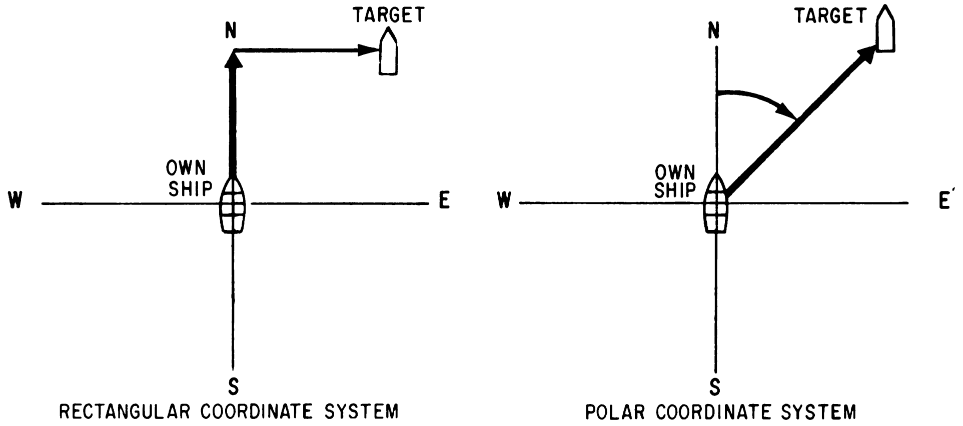

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Figure 5-21.—Coordinate systems.

measured from the reference plane. The deviation can be described by either an angular (elevation) or linear (altitude) value.

When the angle of elevation is used (fig. 5-22), the angle is measured at the origin. One side of the elevation angle is in the reference plane. The other side, the line R, connecting the origin with the target, is in a slant plane.

The line, Rv, establishes point P in the reference plane. Rv is constructed perpendicular to the reference plane; thus, point P is directly beneath the target. The polar coordinate, Rh, and the bearing angle, ϕ, describe the position of point P in the reference plane. The third coordinate, describing the target's position with respect to the reference plane, is the measured angle of the target's elevation.

The position of the target in figure 5-23 can be described by three linear coordinates. First,

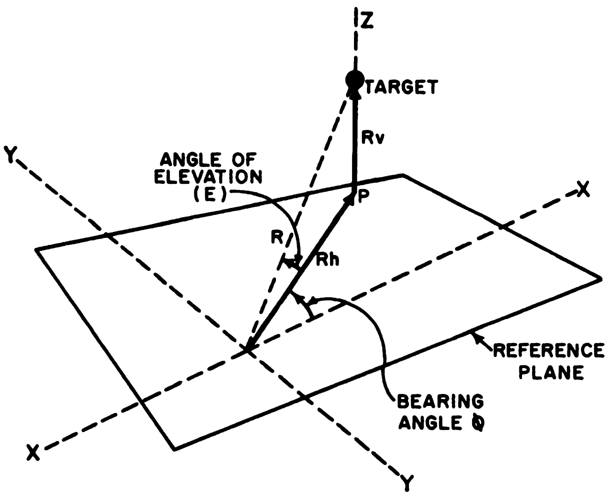

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Figure 5-22.—Three-dimensional polar coordinate system.

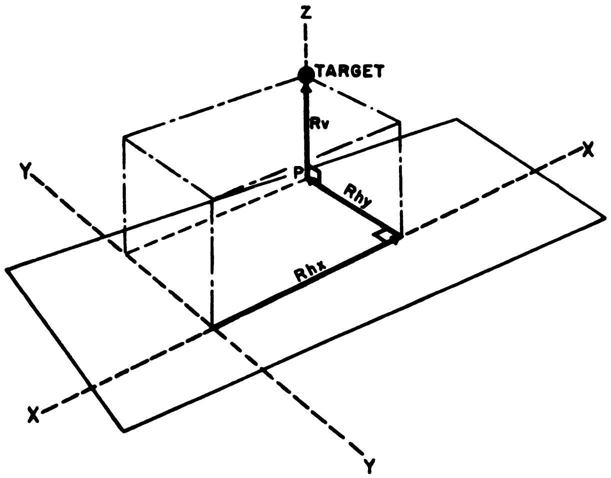

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Figure 5-23.—Three-dimensional rectangular coordinate system.

establish point P in the reference plane, directly beneath the target. The position of point P can be described by the rectangular coordinate (Rhx, Rhy). The altitude, Rv, is the third coordinate used to describe the target's position. The altitude is measured along an axis perpendicular to the reference plane. This axis is usually labeled with the letter Z, and called the Z axis.

UNITS OF MEASURE

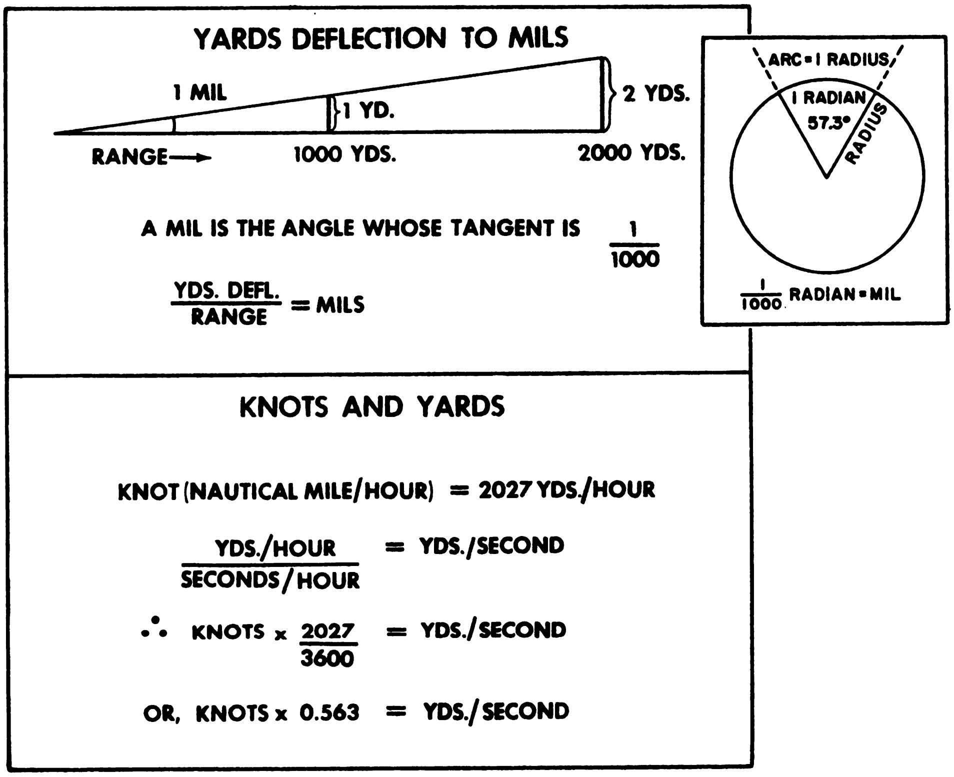
Target position can be described by the linear measure of miles or yards, and by the angular measure of degrees and minutes of arc. The definition of these units is general knowledge and requires no explanation here. But you should be familiar with all the units of measure used in the coordinate systems. The units include angular and linear measure, and rates of motion.

We will start with the knot, which is a linear rate of motion equal to a nautical mile per hour. Ownship speed, target speed, and wind velocity enter the problem measured in knots. The knot, however, is too large a value both in distance and time for use in the problem, and is converted to an equivalent rate in yards per second. A linear rate is equal to the distance traveled divided by the time it takes to cover the distance.

Since there are 2,027 yards in a nautical mile and 3,600 seconds in 1 hour, the formula (fig. 5-24) for converting knots to yards per second is:

$$1 \text{ knot} = \frac{2027 \text{ yards/hour}}{3600 \text{ seconds/hour}}$$

The hours cancel, and working the formula leaves 1 knot = 0.563 yards per second. Hence, a



KNOT (NAUTICAL MILE/HOUR) = 2027 YDS./HOUR

$$\frac{\text{YDS./HOUR}}{\text{SECONDS/HOUR}} = \text{YDS./SECOND}$$

$$\therefore \text{KNOTS} \times \frac{2027}{3600} = \text{YDS./SECOND}$$

OR, KNOTS x 0.563 = YDS./SECOND

55.145

Figure 5-24.—Mils, knots, and yards.

ship moving at 1 knot travels 0.563 yards in 1 second. The value, 0.563, is a constant ratio used to convert between knots and yards per second. (When mentally converting between yards and nautical miles the number of yards is rounded off to 2,000. This is an acceptable practice.)

Linear rates are used to describe a motion along a straight line. An angular rate is the speed with which an angle is changing. For example, assume that you are tracking an airplane that is flying around your ship so that its flight path forms a circle with your ship in the center. If the plane flies at a constant speed, so that it makes a complete revolution every two minutes, it has an angular rate of 180° per minute, or 3° per second.

Another extremely useful system of angular measure is called radian measure. In radian measure, an arc equal in length to the radius of a circle is measured on the circumference of the circle. When two radii are drawn to the ends of this arc, the angle they enclose is called a radian and is equal to 57 degrees and 18 minutes or 3,438 minutes of arc (fig. 5-24). There are 2π radians in a circle. A radian has a constant angular value that is related to a linear value equal to the length of the circle's radius. Thus, a radian is a convenient unit of measure to convert between angular and linear measure.

The radian, however, is normally too large a unit for use in fire control; instead the MIL which is equal to a thousandth of a radian, or 3.438 minutes of arc, is used. In fire control the target is considered to be moving in a straight line tangent to an imaginary circle whose radius is equal to range. Thus the mil is equal to a thousandth of the range. As range changes, the linear value of the mil changes proportionally, but its angular value is constant (fig. 5-24).

Assume a target, with a linear bearing rate of 100 knots, is being tracked at a range of 10,000 yards. Since the line of sight moves angularly in bearing, the linear rate must be converted to an angular rate. First, convert the knots to yards per second by multiplying the 100 knots by the constant 0.563. This would give a rate of 56.3 yards per second. A mil at 10,000 yards range is equal to 10 yards. Therefore:

$$\frac{56.3 \text{ yards per second}}{10 \text{ yards per mil}} = 5.63 \text{ mils per second}$$

A mil has an angular value and the answer is an angular rate. Note the ease of converting between linear and angular measure with the mil. Knowing the range to a target allows conversion. For this reason, most fire control systems use the mil as the unit of measure in deflection.

To express the rate of mils per second in minutes of arc per second, multiply the number of mils by 3.438, the number of minutes in a mil. The complete formula for converting the linear rate of knots to the angular rate in minutes of arc second is:

$$\text{minutes of arc per second} = \frac{\text{knots} \times .563 \times 3.438}{\frac{\text{range}}{1000}}$$

The three constants in the formula can be combined:

$$.563 \times 3.438 \times 1000 = 1936$$

This leaves the formula:

$$\text{minutes of arc per second} = \frac{\text{knots} \times 1936}{\text{range}}$$

Note that the angular rate is inversely proportional to range. Thus as range changes, the angular rate varies with it. Since range is continuously changing as a target is tracked, this is definitely a disadvantage when there is a need to use the rate to predict the target's future position. Therefore, linear rates are used to predict target future position, while angular rates are used in the target-tracking section of the problem.

STANDARD FIRE CONTROL SYMBOLS

An important step in understanding and solving a fire control problem is the identification of the quantities involved. The symbols used to identify the numerous quantities encountered in fire control are part of the "language" of an FT. Like any other language, you will become more familiar with it through usage. It is almost an impossible task to memorize all of the variations of the basic quantities. However, if you understand how the basic symbols are modified by symbol modifiers and quantity modifiers, you will be able to interpret new symbols when you encounter them. In comparison to the English language, the basic symbols are the nouns and the symbol modifiers and quantity modifiers are the adjectives. As you proceed with solving the basic fire control problem, you will begin to recognize certain quantities and eventually you will have learned the language.

Introduction to OP 1700

OP 1700, "Standard Fire Control Symbols," establishes a system of symbols and definitions for the surface, anti-aircraft, and underwater fire control problems. It includes mathematical quantities associated with the geometrical analysis, and computational and mechanization quantities involved in solving these problems by fire control equipment. Fire control terms, with their accepted definitions, and graphic symbols for mechanical and electrical devices are included. OP 1700 consists of three volumes. Volume 1 contains the symbols for the quantities applicable to solutions of the gun fire control problem. Volume 2 contains the symbols applicable to the underwater problem. Volume 3 contains symbols peculiar to the control of missiles. It is beyond the scope of this training manual to present all of the material contained in OP 1700. However, some of the basic fundamentals and symbols will be presented as background material prior to introducing the fire control problem. This discussion will be concerned only with volume 1.

Volume 1 contains the following four parts.

1. The symbol system explains how symbols are formed, how they are modified to denote special kinds of quantities, and how symbols for new quantities may be constructed.

2. The anti-aircraft related quantities are for use in work on specific parts of the gun fire control problem where it is desired to have on hand all values used to express a basic quantity. Special problems arising in the use of symbols are explained here. Separate chapters are used for the steps of the gun fire control problem.

3. The dictionary of symbols for quantities currently in use, or whose future use may be anticipated, is arranged alphabetically.

4. The appendices of letters with their meanings when used as basic symbols, basic symbol modifiers, and quantity modifiers are also arranged alphabetically.

SYMBOLS AND MODIFIERS–OP 1700.–Volume 1, Appendices A, B, and C, list the Basic Symbols, Basic Symbol Modifiers, and Quantity Modifiers.

The basic symbol (Appendix A) represents the basic geometrical quantity in each class.

The basic symbol modifiers (Appendix B) are used to modify the basic symbols to show the reference of the quantity.

The quantity modifiers (Appendix C) are used to indicate portions of the various quantities. Anytime a quantity modifier is used, the basic quantity will be enclosed in parentheses. The meaning of the quantity modifier depends on whether the modifier is placed in front of, or following, the parenthesis.

Basic Symbols and Modifiers

The basic symbols assigned to represent the basic geometrical quantity in each class, and the letters and numerals used to modify these basic symbols are:

	Basic Symbols
A	Angular Movement (Elevation)
B	Bearing
C	Course
D	Rate of
E	Elevation
Ei	Level
I	Inclination
J	Jump
L	Sight Deflection
M	Linear Movement
P	Gun Parallax Displacement
Ps	Director Parallax Displacement
R	Range
S	Angular Movement (Lateral)
T	Time
U	Velocity
V	Sight Angle
W	Wind Rate
Z	Crosslevel

	Modifiers
a	apparent
b	bearing
d	deck
e	elevation
g	gun
h	horizontal
i	inclination
k	Earth
o	ownship
p	prediction
q	heading
r	range
s	director or line of sight
t	target
v	vertical
w	wind
x	east-west
y	north-south
z	crosslevel
1	present position
2	future position
3	advance position
4	aiming position
5	fuze

A few examples of symbol construction will give a better understanding of how the system works.

Example 1

DMb = Rate of linear movement in bearing
D = Rate of
M = Linear movement
b = bearing

Example 2

DMho = Ownship's speed
D = Rate of
M = Linear movement
h = horizontal
o = ownship

By substituting t for o, we have DMht, the target's horizontal speed.

Example 3

Rp2 = Difference between present range and future range
R = Range
p = prediction
2 = future position

Example 4

By = True target bearing
B = Bearing
y = North/south axis

Example 5

DE = Angular elevation rate
D = Rate of
E = Elevation

All rates are angular unless a linear rate is indicated by the symbol M.

Quantity Modifiers

Besides the geometrical quantities in each class, the portions of these quantities measured to various positions and accounting for various effects are symbolized. Also, in the expression of rates, the frame of measurement of the rate is indicated. These quantity modifiers are applied by enclosing the symbols for the geometrical quantities in parentheses and preceding or following the parentheses with the quantity modifiers. For example, the portion of sight angle Vs, accounting for the effect of wind, is symbolized by enclosing the sight angle symbol Vs in parentheses, and preceding the parentheses with modifier w (meaning portion accounting for wind), forming the symbol w(Vs).

In general, when the modifier precedes the parentheses, it defines the correction to the basic quantity due to the effects of the modifier. If the modifier follows the parentheses, it defines the basic quantity corrected for the effects of the modifier.

The meanings of the letters when used as quantity modifiers of geometrical quantities are:

a	advance
b	ballistics
c	computed or generated
d	designated
e	estimated or error
f	function
g	dead time
i	increments
j	computational addition or partial value
k	Earth
l	initial
m	relative motion
o	ownship
p	gun parallax
ps	director parallax
q	correction input or spot
r	rate control
s	inertial or selected
u	initial velocity loss
w	wind

MOTION

Until now, we have considered ownship and the target as being stationary. This is not the normal situation when your ship is at sea. Let's see how these motions will affect the fire control problem.

Effects of Relative Motion

All of the principles of interior and exterior ballistics that apply to a stationary target and gun also hold true when both ownship and the target are in motion.

When an enemy ship is sighted and comes within range, it is the function of fire control to solve the fire control problem so that your ship's weapons will hit the target. If the enemy were obliging enough to remain in one place and if your ship were also brought to a stop, the required elevation and train angles could be determined by considering only the factors of interior and exterior ballistics for fixed gun and target. No enemy ship would be foolish enough to remain still under fire; and your ship doesn't want to be a "sitting duck" for the enemy's fire either. Therefore, both the target and your own ship will keep moving during battle. As a result, the target range and bearing are continually changing, necessitating constant changes to gun elevation angle and gun train angle.

Referring to figure 5-25, you can see that in order to make the proper corrections, it is necessary to know in what direction and at what speed the target is moving. With this information, it is possible to predict the position the target will occupy after the time of flight of the projectile has elapsed. The weapon is then directed so that the projectile will strike the future position of the target.

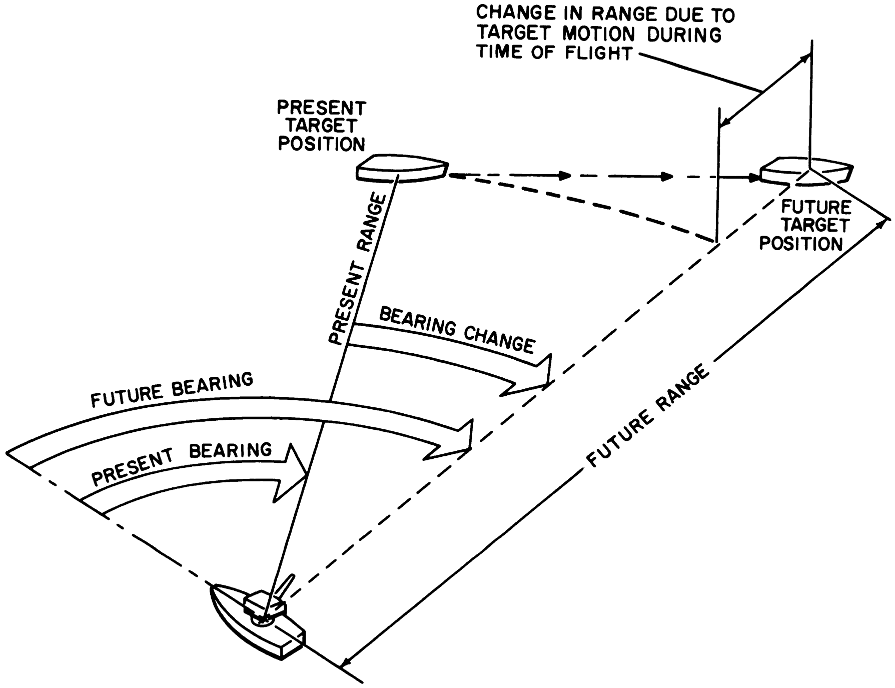
Another factor which must be considered in the fire control problem when both ships are moving is the fact that the velocity of the ship will be imparted to the projectile at the instant of firing, and will affect the trajectory. To illustrate this effect, consider the target as standing still and the firing ship in motion. As the gun is fired, the projectile has two velocities, its own iv and that due to the ship's motion. If the ship's velocity is not considered, the projectile will land short, beyond, or to one side of the target. Where the projectile lands depends on whether the ship is leaving, approaching, or moving laterally with respect to the target. You can see that the effect of ship's speed and direction must be considered to obtain accurate fire.

Effects of Deck Motion

Another factor which enters into the solution of the fire control problem on moving ships is the fact that the deck which supports the gun is very seldom perfectly level. A moving ship requires that corrections be made to gun orders to compensate for deck motion. Deck motion can be resolved into two motions–roll and pitch.

Roll is rotation of the ship from side to side in a plane perpendicular to the deck, through the ship's athwartship's axis.

Pitch is rotation of the ship from bow to stern in a plane perpendicular to the deck, through the ship's centerline.



166.206

Figure 5-25.—How target motion affects range and bearing.

You can visualize that, as the ship rolls and pitches, the line of sight will be displaced. Before the fire control problem can be solved and gun orders computed, the effects of roll and pitch must be measured.

The effect of deck motion on elevation of the line of sight is called level. Level is the angle between the horizontal plane and the deck plane, measured in a vertical plane or a normal plane depending upon the type of stabilizing unit used. Level angle (Ei) is measured in the vertical plane through the line of sight. Level angle (Ei′) is measured in the normal plane through the line of sight. Refer to OP 1700 for complete definitions.

The other effect of deck motion on the line of sight is called crosslevel. Like level, the measurement of crosslevel depends upon the type of stabilizing unit. Crosslevel angles are measured between vertical and normal planes. Crosslevel (Z) is the angle between the vertical plane through the line of sight, and the normal plane through the intersection of the vertical plane through the line of sight and the horizontal plane, measured about the axis which is the intersection of the vertical plane through the line of sight and the horizontal plane. Refer to OP 1700 for complete definitions of crosslevel.

Because the directors and gun mounts are mounted in the deck plane, and therefore train and elevate with respect to the deck plane, the measurements of level and crosslevel are utilized to correct various data. These corrections include deck tilt, deck deflection, and trunnion tilt corrections.

Present target position, as measured by the director, is referenced to the deck plane. Ballistic computations are normally referenced to the horizontal plane. The use of level and crosslevel to correct the deck plane measurements to the horizontal plane for computational purposes is essentially known as deck tilt correction.

Deck deflection and trunnion tilt corrections are essentially the use of level and crosslevel to correct ballistic computations in order to reorient gun orders to the deck plane.

The formulas and methods used are quite complex and vary with the system. For this reason you will not study them at this point in your training.

Effects of Target Elevation

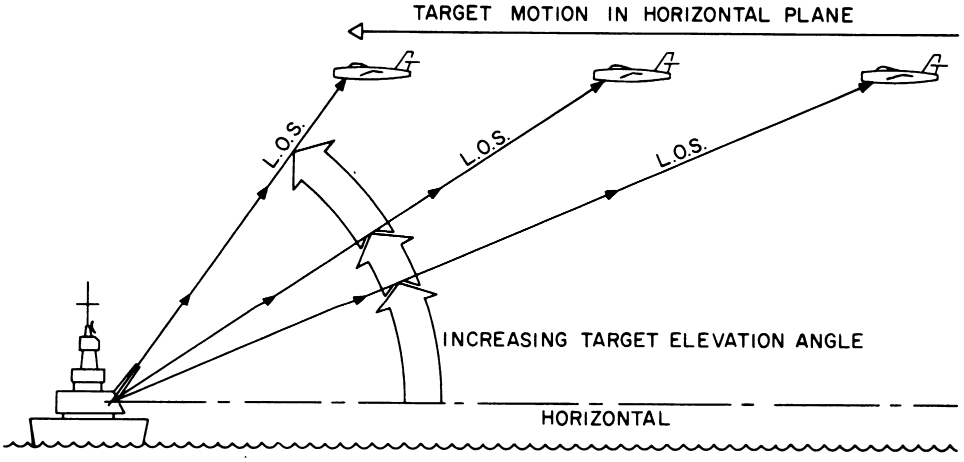
The antiaircraft problem, sometimes called the air problem, is another form or variation of the basic fire control problem. All of the factors that entered into the surface fire control problem must be considered in stating the air problem. The air problem is further complicated by the fact that the target is moving at high speed and may be either climbing or diving.

In the surface problem, the target elevation angle (between los and horizontal) was zero because both ownship and target were on the ocean's surface, and the los, for all practical purposes, was in the horizontal plane. Air targets, however, are ordinarily well above the ocean's surface, so that the los makes an appreciable angle with the horizontal. In addition, if the air target is approaching or leaving ownship in a horizontal plane, the los must be elevated or depressed to keep the target in view. Thus, target elevation angle continually increases or decreases, and as it does so the gun elevation order must be correspondly altered. This effect is shown in figure 5-26.

As shown in figure 5-27, target elevation angle is determined by measuring director elevation at the director and combining this with the level angle measured by the stable element.

If we continue to consider the air target approaching the ship in a horizontal plane, it can be seen in figure 5-28 that slant range from the director to target along the los decreases as the target nears ownship. The reverse is true when the target is moving away from the ship. It is slant range which is measured by the range finder or the radar. Both target elevation angle and range affect gun elevation order. They determine, along with the other ballistic corrections, what the sight angle (angle between the los and the lof) must be in order for the projectile to intercept the target.

It has been shown how an air target moving horizontally above the ocean affects the fire control problem for air targets. The fact that the air target may also be climbing or diving must also be considered. Figure 5-29 shows the effect of the target's vertical motion on gun elevation order. Consider a target which is moving only in a vertical plane so that the horizontal range from the ship is constant. The target elevation angle and the slant range both increase as the height of the target above the Earth increases, and vice versa.


TARGET MOTION IN HORIZONTAL PLANE
L.O.S.
L.O.S.
L.O.S.
INCREASING TARGET ELEVATION ANGLE
HORIZONTAL

166.207

Figure 5-26.—Effect of moving target on target elevation angle.

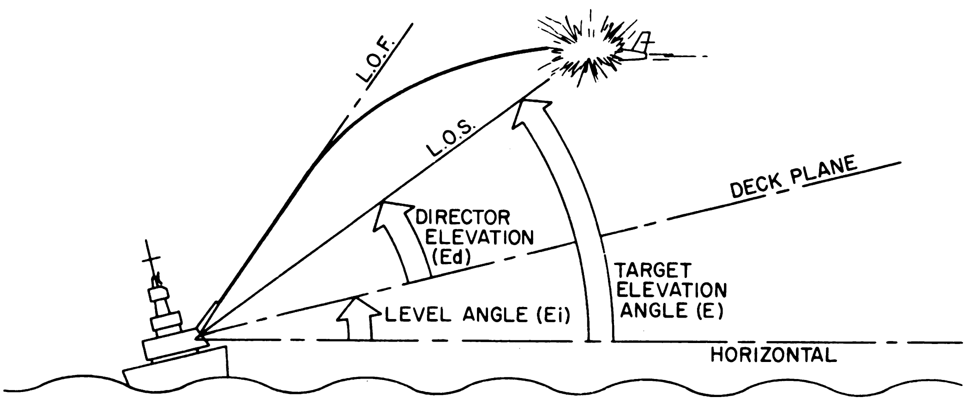


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Figure 5-27.—How target elevation angle is determined.

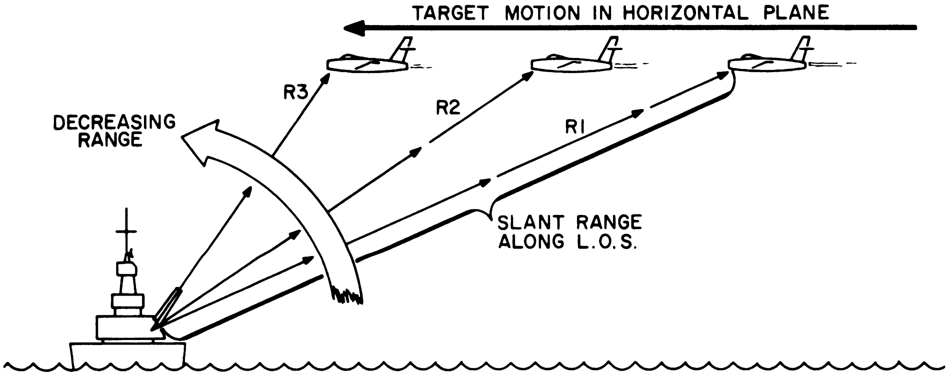

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Figure 5-28.—Effect of moving air target on range.

Of course, in actual practice, air targets will move both horizontally and vertically. Regardless of target motion, the anti-aircraft fire control system must be able to predict the future target range, bearing, and elevation, and make the necessary corrections to sight angle and sight deflection. You will recall that sight angle was defined as the angle between the los and the lof. Sight angle is the main factor which is added to director elevation to obtain gun elevation. Sight deflection is also an angle between los and lof, and is added to director train to obtain gun train.

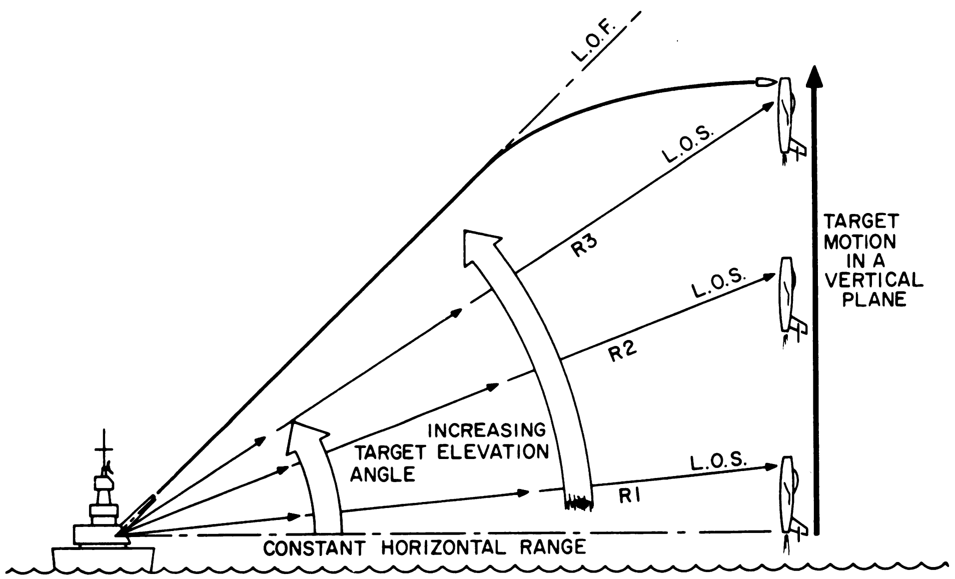
SOLVING THE FIRE CONTROL PROBLEM

As mentioned earlier, the steps in the solution of the fire control problem are:

1. Determining present target position in relation to ownship

2. Predicting future target position in relation to ownship

3. Stabilizing the various units



166.210

Figure 5-29.—How vertical target motion affects target elevation angle and range.

4. Calculating required corrections to gun train and elevation orders

5. Transmitting the data to the delivery device

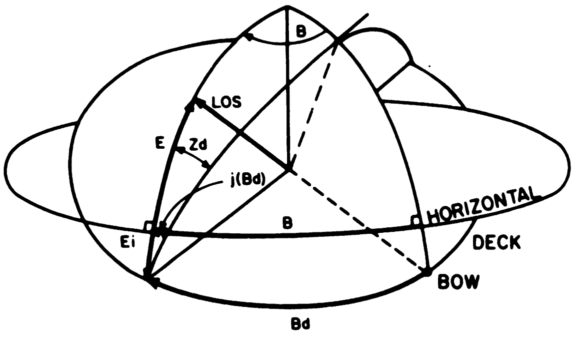
There are variations in fire control problems and the methods by which they are solved. The references may vary from system to system, however, the same basic quantities are involved. In the material which follows, the Mk 68 GFCS will be used to illustrate the solution of the fire control problem. The fire control problem as solved by the computer is complex. Drawings will be used to illustrate the various steps in the solution. The solution of any fire control problem requires that a reference be established. In the Mk 68, as in most fire control systems, the horizontal plane will be the reference. Because the director is mounted in the deck plane, target position measured by the director is with respect to the deck. Conversion from deck to horizontal reference requires that director train Bd and director elevation Ed be modified by level Ei and crosslevel Zd which are measured by the stable element. The stable element is constructed in such a manner that crosslevel is measured with respect to the deck plane. Refer to OP 1700 and note the difference between crosslevel Zd and crosslevel Z.

PRESENT POSITION COMPUTATION

The present position section of the computer performs the following functions:

1. Converts target position from the deck plane to the horizontal plane
2. Compares target position with generated target position
3. Computes angular rates from the errors obtained in the above comparison
4. Determines linear rates for use in the prediction and ballistic section
5. Recombines the linear rates in order to generate continuously varying estimates of target present position
6. Computes the stabilization aids for the director

The geometrical values involved in conversion from the deck plane to the horizontal plane are shown in figure 5-30.



166.211
Figure 5-30.—Spherical coordinate diagram.

When the deck plane and the horizontal plane coincide, relative target bearing (B) and director train (Bd) are equal. With the deck tilted by some amount (measured as level and crosslevel) and Bd at some angle other than 0° or 180°, a deck tilt correction, j(Bd), is computed. B = Bd + j(Bd). The correction j(Bd) is dependent on both Ei and Zd. The addition of ship's course (Co) to B produces true target bearing By. Level Ei is subtracted from director elevation Ed to produce target elevation E.

With the target located in the horizontal plane, the next step is to compute horizontal range Rh and target height Rv. The quantities Rh and Rv will be used in later calculations. Figure 5-31 illustrates the problem.

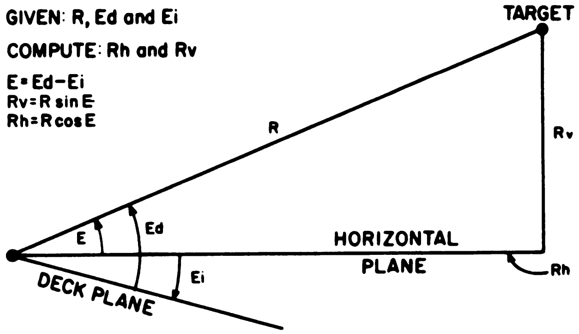


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Figure 5-31.—Rectangular coordinate values of target position.

Another step, computation of linear rates in and across the los, is shown in figure 5-32. Ownship motion is represented by a vector whose magnitude is ship's speed DMho, and whose direction is relative target bearing B. Target motion is represented by a vector whose magnitude is target speed DMht, and whose direction is target angle Bot. Each vector is resolved into two components in the horizontal plane. One of these components will be along the line of sight and the other will be perpendicular to the line of sight. Horizontal range rate DMrh is found by algebraically adding the components along the los. The rate of linear movement in bearing (DMb) is found by algebraically adding the components perpendicular to the los.

As shown in figure 5-33 and 5-34, target motion must also be considered in the vertical plane. The rate of climb (DMv) measures the target's rate of vertical linear movement in elevation. DMrh, found previously, is used with DMv to construct the diagram in the vertical plane through the los. Components along the los are added to produce present range rate (DMr).

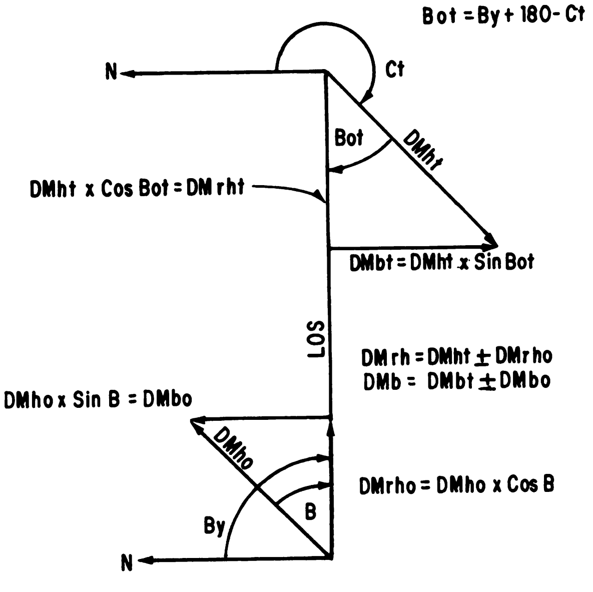

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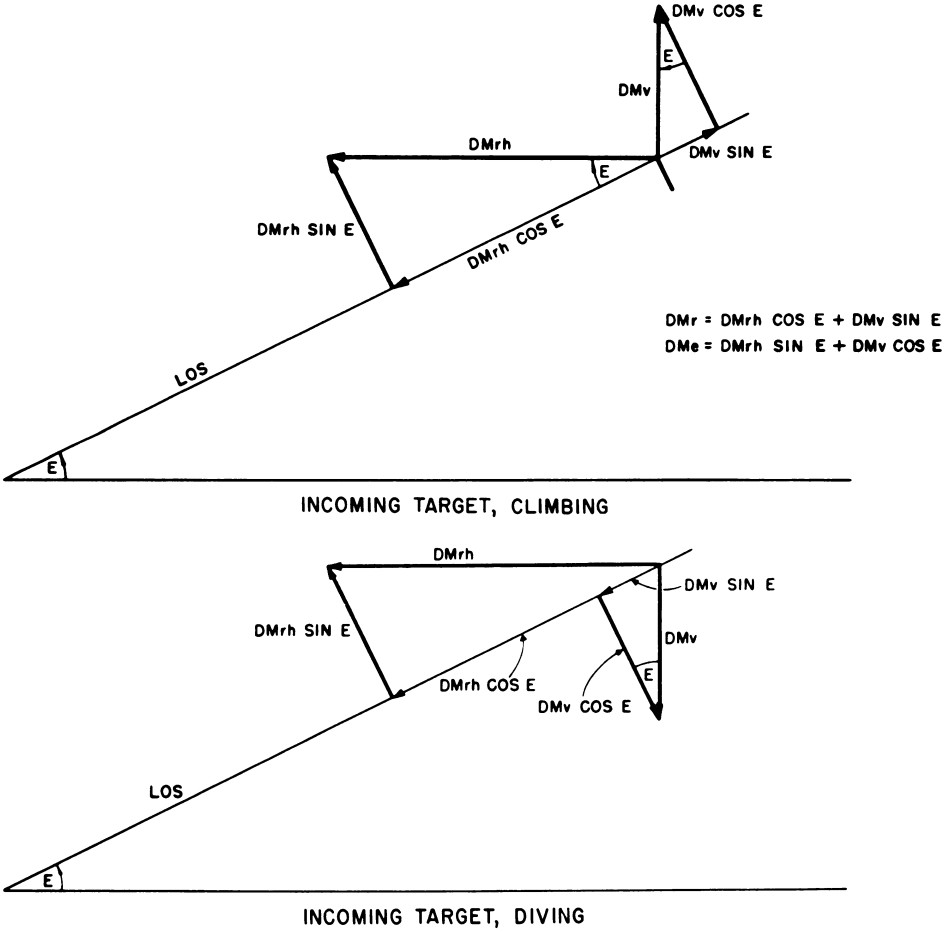
Figure 5-32.—Fire control problem horizontal plane.



166.214

Figure 5-33.—Fire control problem—vertical plane.

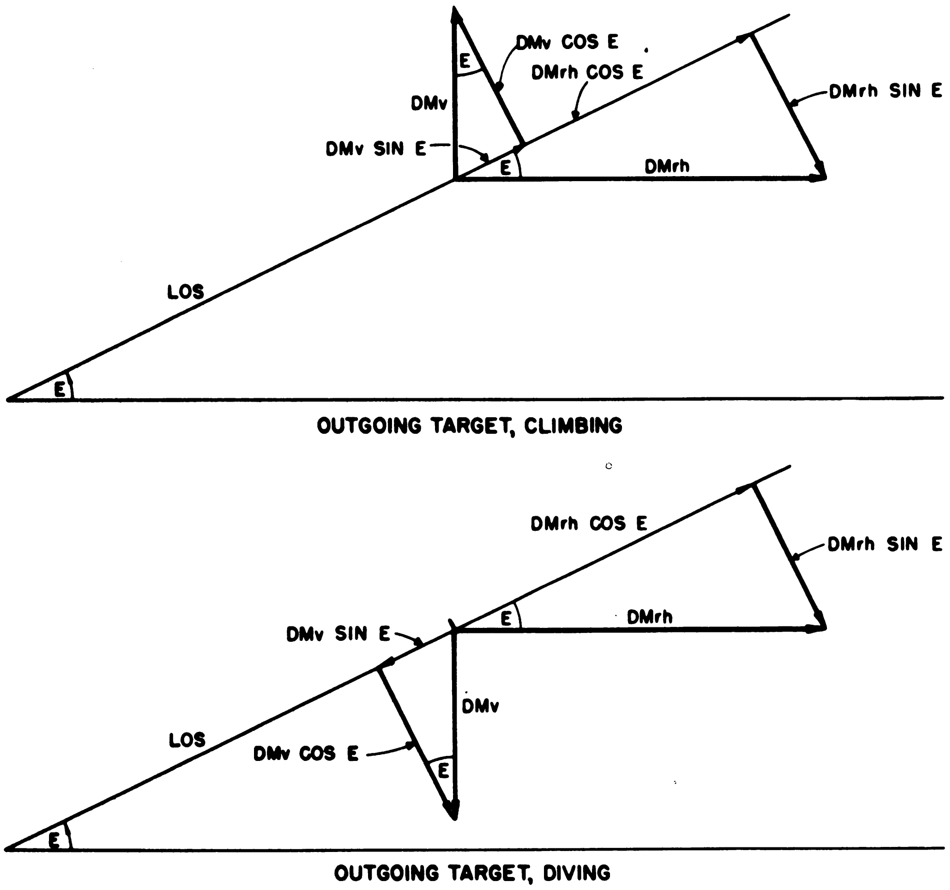
Components perpendicular to the los are added to produce the rate of linear movement in elevation (DMe).

The present position section of the computer also resolves true wind in and across the los, as shown in figure 5-35. The magnitude of the true wind vector is wind speed Wh and the direction of the vector is true direction of true wind (Bwy).

With high speed air targets, little time is allowed for engagement. It is necessary, therefore, for the computer to act rapidly and completely automatically to determine the target course, speed, and rate of climb. These quantities, Ct, DMht, and DMv, must be determined by the computer. The computer uses a process called rate control to determine these quantities. The process is quite involved and will not be discussed in this RTM. Basically, what is done is to compare generated values against computed or observed values. The difference or error in the comparison is a rate control signal used to correct the generated values.

PREDICTION AND BALLISTIC COMPUTATION

The function of the prediction and ballistic section is to compute a line of fire (lof) which is



166.215

Figure 5-34.—Fire control problem—vertical plane.

oriented with respect to the los and the horizontal plane. This section computes:

1. The position the target will occupy at the end of the time of flight

2. The amount the guns must lead this point so the projectile will hit the target

As shown in figure 5-36, future position is determined by first multiplying the relative motion rates DMv, DMrh, and DMb by an assumed time of flight, T2, and combining the linear quantities with present target position values Rh and Rv. The solution of correct T2 will be discussed later.

Calculation of gun bearing Bg and gun elevation Eg requires corrections for the various ballistic and motion quantities. The illustrations in figure 5-37 and figure 5-38 show the line of fire.

In figure 5-37, horizontal deflection Lh is obtained by combining horizontal angular motion Sh and wbq(Lh), the total horizontal deflection angle due to wind, drift, and spot. Lh, if combined with relative target bearing B, would produce relative gun bearing Bg. In the Mk 68, however, these quantities are not combined in the prediction and ballistics section but will be utilized in the trunnion tilt section.

Gun elevation Eg is the sum of target elevation aiming position angle (E4) and superelevation angle (V4), (fig. 5-38).

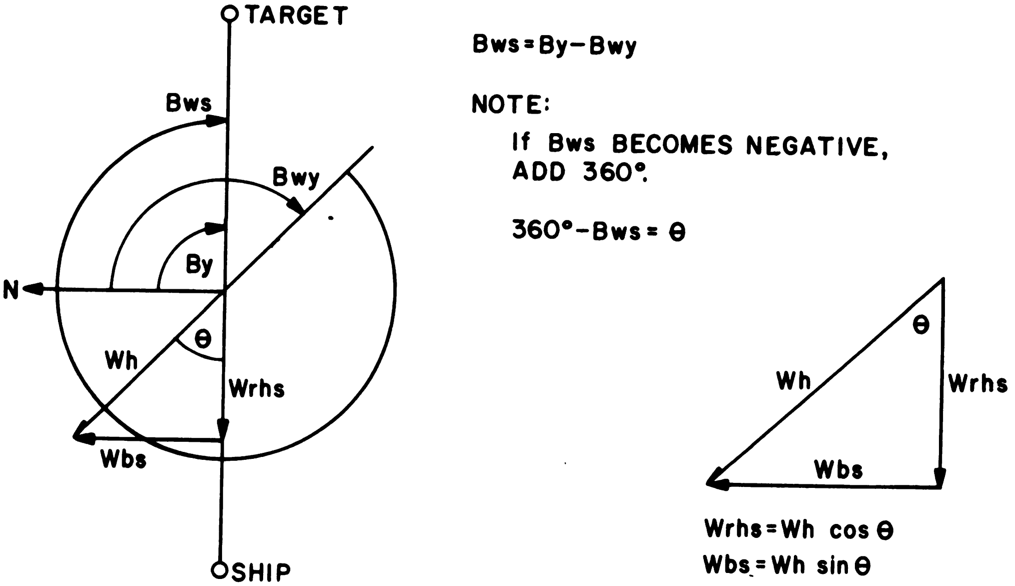


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Figure 5-35.—The los components of true wind.

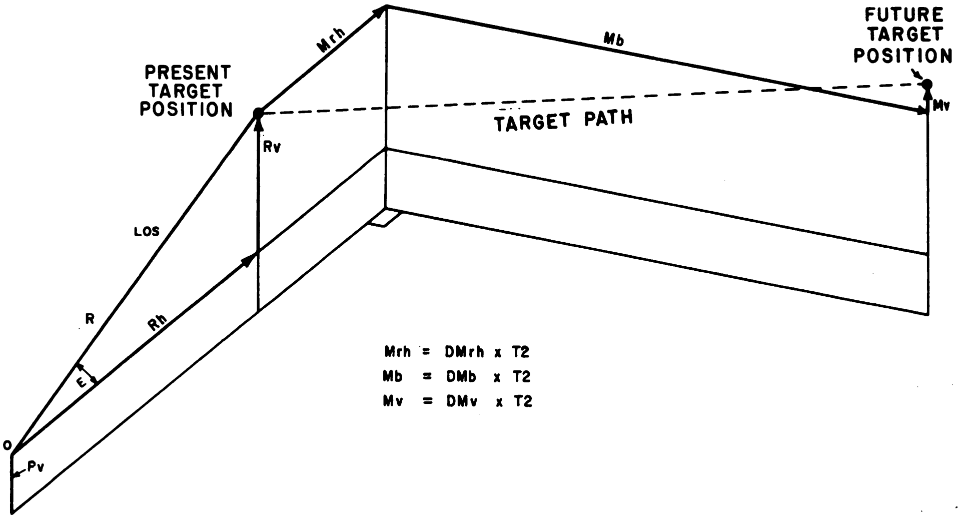

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Figure 5-36.—Establishing future target position.

E4 is determined by the solution of a triangle formed in the following manner. Target height Rv, vertical parallax displacement Pv, and vertical linear movement Mv are combined to form H4, the side of the triangle opposite E4. The adjacent side is the horizontal range to the aiming point (Rh4).

V4 is determined by the solution of a triangle formed in the following manner. Superelevation for normal conditions, b(V4);

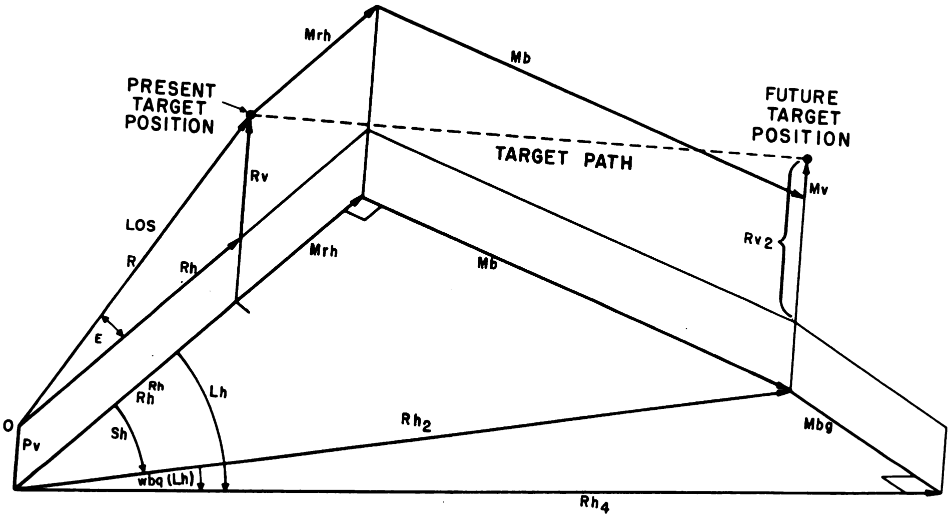

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Figure 5-37.—Line of fire in horizontal plane.

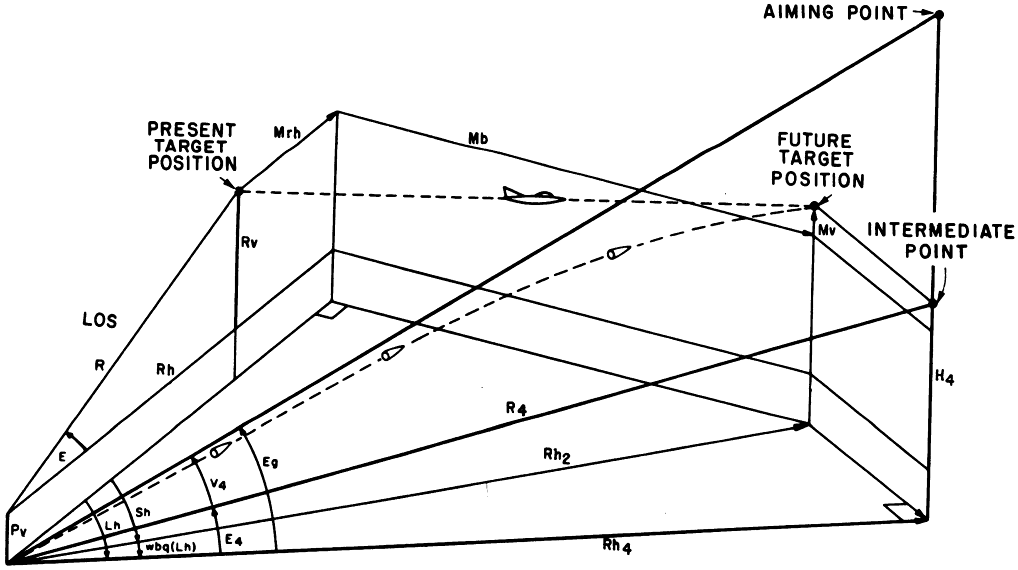

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Figure 5-38.—Line of fire in vertical plane.

corrections and partial corrections to superelevation due to initial velocity, u(V4); air density, x(V4); apparent wind, w(V4); and elevation spot, q(Eg) are combined to form the side opposite V4. The adjacent side is aiming point range, R4. Note: q(Eg) is not used for air targets.

Time of flight T2 is calculated in this section by a closed loop system. The assumed value of T2 is compared to R4 and E4 and corrected until it agrees. Corrections for wind, initial velocity, and air density are applied to T2 and the preceding process for computing T2 is repeated.

TRUNNION TILT AND PARALLAX COMPUTATION

The trunnion tilt section computes the gun orders which are transmitted to the gun mounts. The guns are mounted on trunnions which provide the axis about which the guns are free to move in elevation. The trunnions are rotated as the mount is trained. Unless the deck plane and horizontal plane coincide (Ei and Zd = 0), the quantities Lh and Eg must be modified to make up gun orders Bdg′ and Edg′. Figure 5-39A and B illustrate the effect of and the correction for trunnion tilt. Gun train order Bdg′ and gun elevation order Edg′ are transmitted to the guns by synchros.

If all guns were physically located at the reference point (the director), projectiles fired from the guns would hit the target without further correction. The guns are, of course, not located at the reference point but are some distance forward or aft of the reference point and also below it, since the director is located high on the superstructure.

The parallax difference due to the height of the director above the guns is considered in the problem as a portion of advance position height, H4, and therefore affects the computation of advance elevation position angle, E4, and consequently gun elevation order Edg′ as it is transmitted by the computer. This height difference is considered the same for all guns, 10 yards.

As shown in figure 5-40, another quantity must be added to Edg′ to compensate for the horizontal displacement of the guns from the director. The nomenclature for this quantity, as transmitted by the computer, is pl(Edg′)h. This can be broken down as follows:

1. The Edg′ in parenthesis shows that the quantity is a correction to gun elevation order.

2. The quantity modifier p denotes a parallax correction.

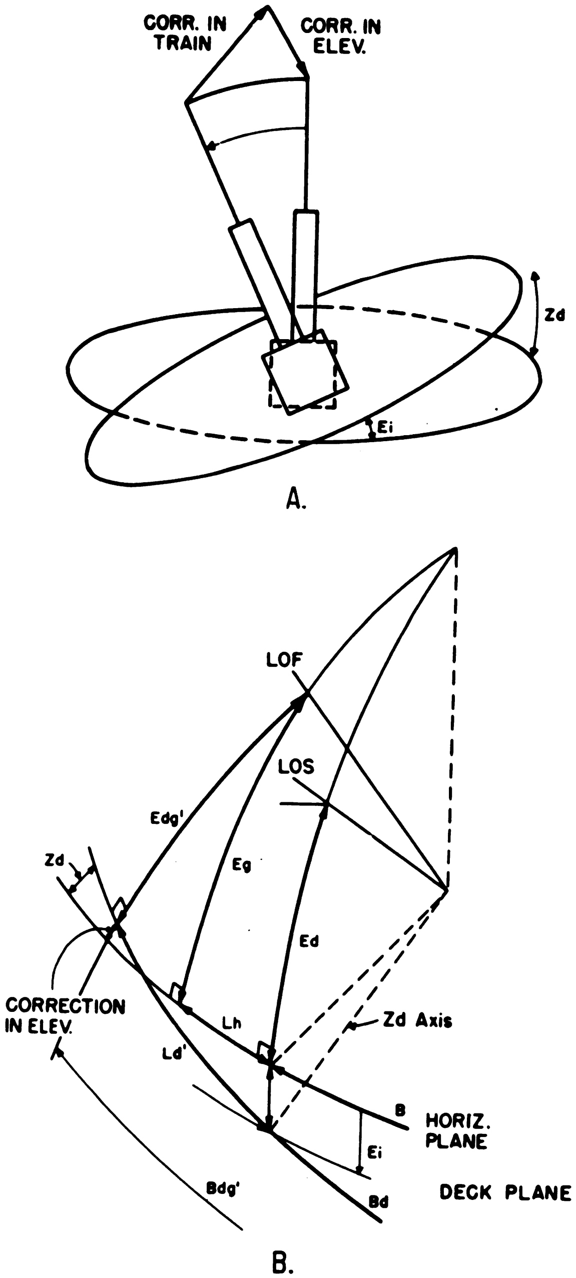

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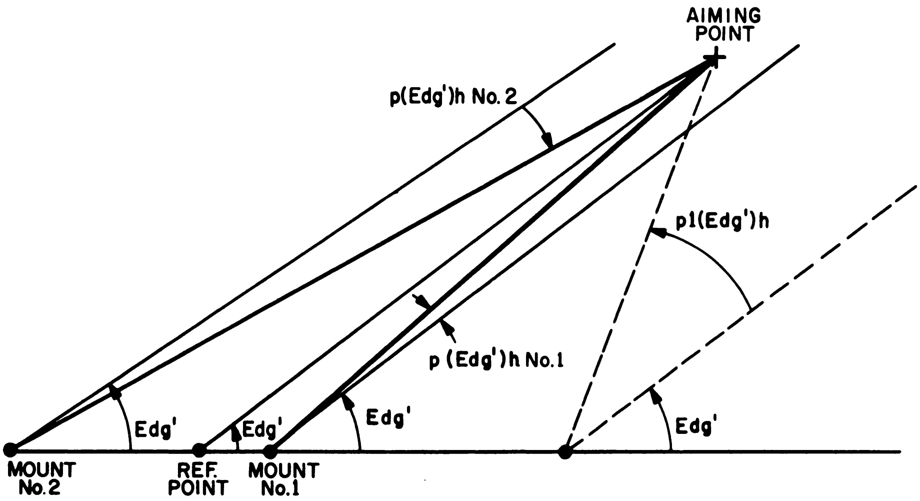
Figure 5-39.—A. Effects of trunnion tilt. B. Corrections for trunnion tilt.

3. The numeral 1 used as a quantity modifier means unit parallax, or that parallax correction necessary for a 100-yard parallax base length forward of the reference point.

4. The quantity modifier h means that this correction is due to a horizontal displacement of



166.221

Figure 5-40.—Effects of elevation parallax correction.

the gun from the director. The quantity transmitted is therefore unit elevation parallax correction, pl(Edg')h.

When computing pl(Edg')h, three quantities already computed must be considered. These three variables are E4, R4, and Bdg'. These quantities are used as follows:

1. Since the guns are mounted along the base length fore and aft of the director, it can be seen that pl(Edg')h will be zero when elevation is zero and would have to compensate for the entire base length error at 90°. This means that pl(Edg')h must vary as the sine function of elevation angle. The value used is sine E4, the sine of target elevation aiming position.
2. Parallax errors decrease as range increases and conversely increase with a decrease of range. Causing the correction to change with the reciprocal of R4, aiming range, compensates for this.
3. The correction to Edg' will also vary as the cosine of Bdg', gun train order, since it will be zero at the beams and maximum fore and aft.

All of the guns are not, of course, 100 yards forward of the director. The direction of the correction is reversed in transmission to mounts aft of the director. Only that portion of unit parallax needed for the actual base length of the gun from the reference is used as a correction to Edg'. The amount is selected through the use of change gears in the receiving unit of the gun mount. The correction is now represented as p(Edg')h, the numeral 1 having been dropped as a quantity modifier since the unit base of 100 yards is no longer used.

As shown in figure 5-41, the horizontal displacement of the guns fore and aft from the director also necessitates corrections to Bdg', gun train order, as used by the individual guns. The basic correction transmitted by the computer is pl(Bdg'). This can be broken down as follows:

1. Bdg' in parenthesis denotes a correction to be applied to the gun train order.
2. The quantity modifier p denotes a parallax correction.
3. The numeral 1 used as a quantity modifier denotes unit parallax computed for a base length of 100 yards.

The quantity transmitted is pl(Bdg'), unit train parallax due to horizontal base.

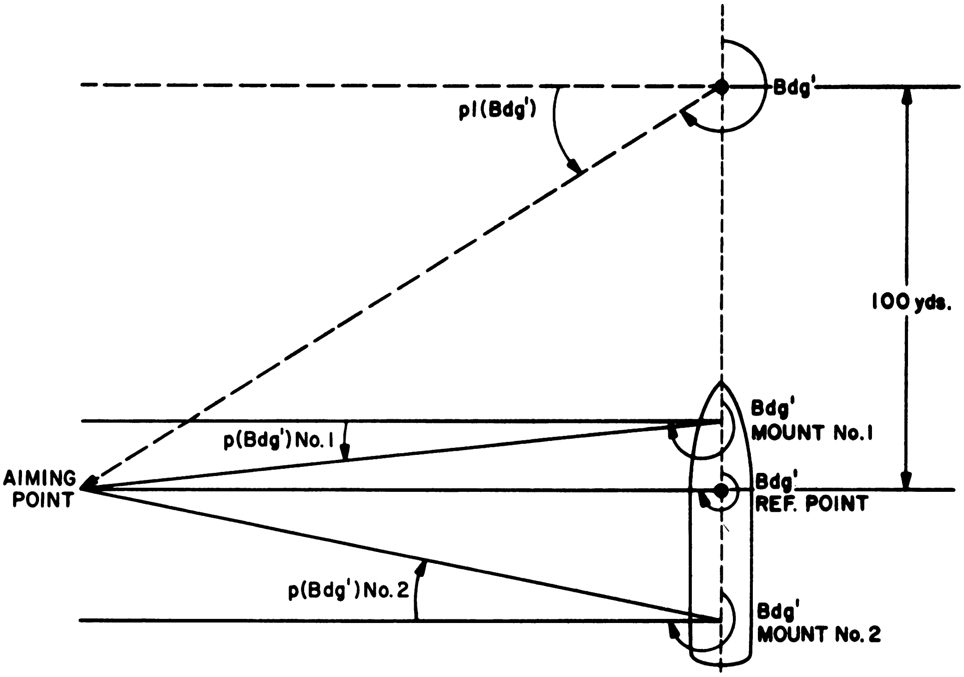


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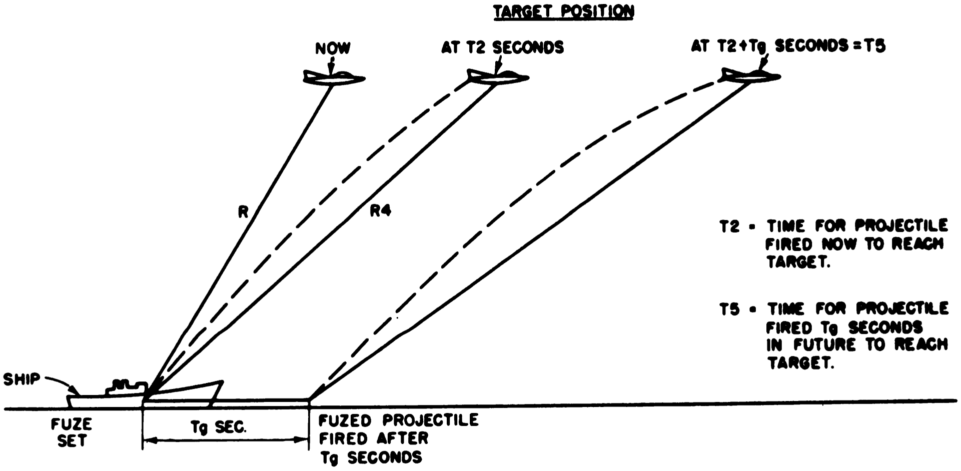
Figure 5-41.—Effects of train parallax corrections.


TARGET POSITION
NOW
AT T2 SECONDS
AT T2+Tg SECONDS = T5
R
R4
T2 • TIME FOR PROJECTILE FIRED NOW TO REACH TARGET.
T5 • TIME FOR PROJECTILE FIRED Tg SECONDS IN FUTURE TO REACH TARGET.
SHIP
FUZE SET
Tg SEC.
FUZED PROJECTILE FIRED AFTER Tg SECONDS

166.223

Figure 5-42.—Fuze computation.

When computing pl(Bdg′), the three variable quantities that must be considered are R4, E4, and Bdg′. They are used as follows:

1. pl(Bdg′) is caused to vary with the reciprocal of R4.

2. Since train parallax errors are maximum on the beams, and zero fore and aft, pl(Bdg′) varies as the sine of Bdg′.

3. pl(Bdg′) must increase as target elevation position angle increases. In this case the secant function of E4 is used for that increase because the gun is trained in the deck plane.

The unit parallax quantity, pl(Bdg′), is corrected in the receiving unit of the gun mount for actual parallax base length of the gun and direction of correction. Change gears pick off the correct amount and synchro receiver connections are such that the correction is applied in the proper direction. The quantity then becomes p(Bdg′), the numeral 1 having been dropped to show that the quantity is no longer unit parallax.

FUZE COMPUTATION

The function of the fuze computer is to compute a fuze order setting T5. If the fuze could be set at the instant of firing, T5 would be equal to time of flight T2. Unfortunately, there is some delay. The delay is dead time, Tg. Figure 5-42 illustrates the problem to be solved. Tg is the time lost between setting the fuze and loading the projectile.

Computation of the fuze order completes the sequence for solving the fire control problem. Only major steps of the solution were illustrated. However, you should at this time have a good general understanding of the problem and how fire control equipment solves the problem.

CHAPTER 6

FUNDAMENTALS OF ANALOG COMPUTERS

INTRODUCTION

Analog computers are instruments that accept information and perform mathematical and logical operations in a systematic order at high speeds. The mathematical operations include summation (addition and subtraction), division, multiplication, vector analysis, and other mathematical manipulations.

There are two distinct branches of the computer family. One branch is descended from the abacus, a mechanical extension of the idea of finger (digit) counting. It uses digits in the form of pulses and the absense of pulses to express numbers, and is therefore called a digital computer. In other words, it simply counts.

The other member of the computer family, the ANALOG computer, measures some continuous quantity such as the value of a voltage. The measured voltage represents, mimics, simulates, or, to use a more elegant word, is analogous to some quantity such as distance, speed, angle, weight, or time.

The analog computer (fig. 6-1) makes the necessary calculations to aim the gun from the deck of a moving, pitching, and rolling ship, so as to hit a moving target. In other words, it solves the fire control problem discussed in chapter 5.

Analog computers may produce answers in either a numerical or physical form. Physical form means voltages, or shaft and gear revolutions and positions. The principles here are similar to those discussed in the chapter on data transmission. Because analog computers can quickly solve interrelated equations simultaneously, they are used to direct gun fire.

An analog computer is an assembly of basic computing elements, none of which are difficult to comprehend. Each computing element solves its own problem. The study of the fire control problem and the basic computing elements leads to an understanding of the computer. To know the whole, you must know its integral parts. This is the approach taken in the study of the analog computer in this course.

An analog computer simulates a mathematical problem in a physical system. In other words, the mathematical problem is duplicated by using mechanical, electrical, and electronic computing elements. The physical values in these systems (voltages and shaft revolutions or positions) are measurable. This is a rather abstract idea, so we will illustrate it. As an example, we will use the computation for future target height (Rv_2). The formula for Rv_2 is

$$Rv_2 = R \cdot \sin E + T_2 \cdot DMv$$

Where:

R = present range
E = present elevation
T_2 = time of flight
DMv = linear rate at which target height is changing

Solving the formula requires four separate operations:

1. Find sin E
2. Multiply sin E by R
3. Multiply T_2 by DMv
4. Add R sin E and T_2 DMv

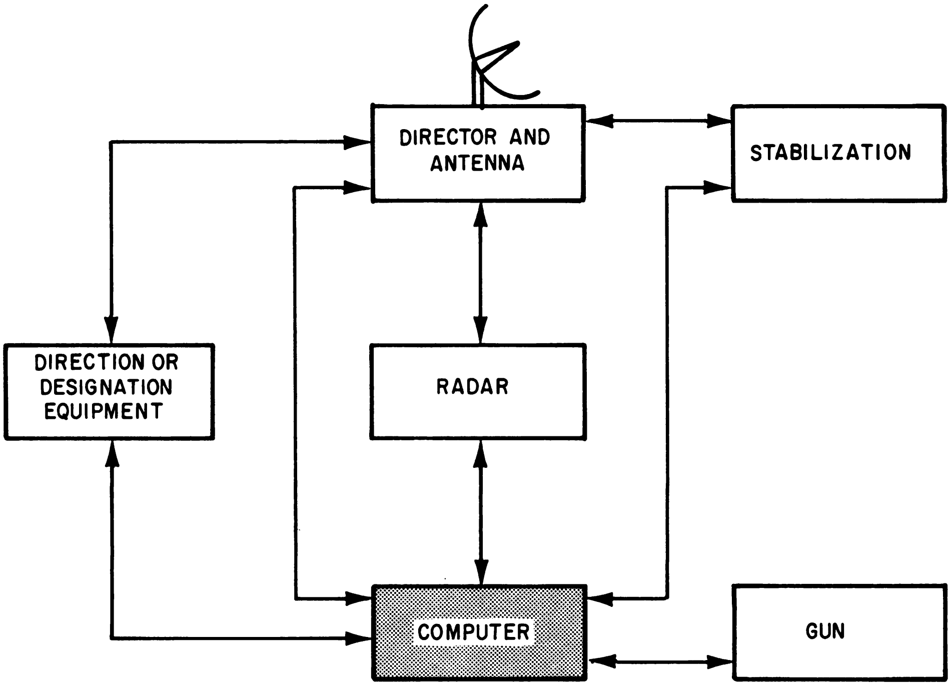


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Figure 6-1.—Analog computer.

In figure 6-2 these operations are shown in an arrangement similar to that found in a computer. The mathematical functions are shown in block form. By substituting computing elements, the formula can be mechanized. R and E are measured by the director, and are known quantities. T_2 and DMv are computed quantities which are assumed to be correct, because they enter the formula with definite values.

Each computing element in the figure solves a discrete problem which is an integral part of the overall problem. There is practically no delay in the elements arriving at an answer; once its inputs are set, the answer is present as an output. The input values of R and E are represented by a voltage and an angle, respectively. An infinite number of combinations of these values are possible, but they can be represented quickly and accurately in their analogous systems. As a target moves in or out along the range scale, its voltage representation follows it in a linear manner along the voltage scale. The voltage, within its limits of operation, is a continuous, uninterrupted representation of the numerical value of range. Thus, although there are two dynamic input quantities, the answer is always available.

INTRODUCTION TO SCALE FACTORS

Before an analog computing element can solve a mathematical problem, its movements or voltages must be assigned numerical values.

At one time or another, you have probably used a road map to estimate the distance from one point to another. Usually, at the lower edge of the map, there is a scale, which is graduated in miles per inch. This ratio is called a scale factor. It states the ratio of the actual area that the map represents to the scaled drawing. By measuring the distance between points in inches

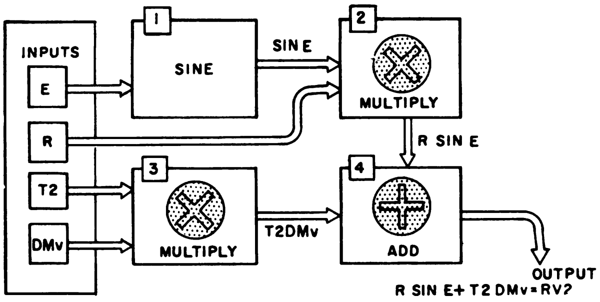

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Figure 6-2.—Mathematical operations.

and multiplying this number by the miles per inch (mi/in), obtained from the scale, you get an estimate of the number of miles between points.

Another familiar example of scale factor is the mileage indicator in an automobile. Here, during design, the engineer determines how far the car will move for one revolution of the drive shaft, connects a counter to it, and then scales the counter to represent the distance the car is driven. In reality, all the counter is doing is counting the drive shaft revolutions. Here, the scale factor is the ratio of the distance covered to one revolution of the drive shaft.

Just as the inches on a road map and the revolutions of the drive shaft are used as scaled factors to represent some physical knowledge, the elements of an analog computer are scaled to represent physical quantities within the computer.

A scale factor, selected for use in an analog computer, is a constant that relates a computer variable directly to a variable of the problem being solved. In other words, it is the ratio of the analog units to the equation units. Thus,

$$\text{Scale Factor} = \frac{\text{Analog Units}}{\text{Equation Units}}$$

The most commonly encountered analog units are volts (V) and shaft revolutions (r). These analog units are used to represent the physical variables (or equation units) of the fire control problem, such as range, elevation, bearing, speed, initial velocity, and many others.

The larger the scale factor is, the more accurate the results will be, or the larger the ratio of analog units to equation units the more accurate the results. When this statement is applied to scale factors in an analog computer, it can be illustrated in the following examples.

Example 1: If one revolution of a shaft represents 360°, that shaft has a smaller scale factor than one revolution of another shaft representing 10°.

$$\text{scale factor} = \frac{\text{analog units}}{\text{equation units}}$$

$$\text{scale factor} = \frac{1\ \text{r}}{360^\circ}$$

$$\text{scale factor} = 0.00277\ \text{rev/deg.}$$

$$\text{scale factor} = \frac{\text{analog units}}{\text{equation units}}$$

$$\text{scale factor} = \frac{1\ \text{r}}{10^\circ}$$

$$\text{scale factor} = 0.1\ \text{rev/deg.}$$

Since 0.00277 is less than 0.1, the scale factor for a shaft representing 360° is smaller than for one representing 10°.

Example 2: If 1 volt represents a distance of 100 yards (yd), the scale factor is larger than when 1 volt represents 1,000 yards.

$$\text{scale factor} = \frac{\text{analog units}}{\text{equation units}}$$

$$\text{scale factor} = \frac{1\ \text{V}}{100\ \text{yd}}$$

$$\text{scale factor} = 0.01\ \text{V/yd}$$

$$\text{scale factor} = \frac{\text{analog units}}{\text{equation units}}$$

$$\text{scale factor} = \frac{1\ \text{V}}{1{,}000\ \text{yd}}$$

$$\text{scale factor} = 0.001\ \text{V/yd}$$

Since 0.01 is larger than 0.001, the scale factor for 1 volt representing 100 yards is larger than when 1 volt represents 1,000 yards.

The actual scale factor used in analog computers depends upon the voltage suitable for the computer circuits. In most computers, a variable in an equation is represented by as large an electrical or mechanical quantity as possible. This gives a larger analog unit to equation unit ratio, thereby increasing accuracy.

When the terms large scale factor and small scale factor are used in later discussions, you should have a clear concept of their meaning.

CHOICE OF SCALE FACTORS

In electronic computing elements, circuit noise affects the values. The saturation point of amplifiers also limits the scale factor values. On the other hand, if the scale factor is too large, the size of the resistors, condensers, and other components in the circuit would have to be increased in order to handle the increased power required. This would also create a problem of heat dissipation.

The problem of selecting a scale factor, for electronic elements, is illustrated by the following example.

Consider a scale factor of 1 volt per 4,000 yards. One millivolt (average) of noise in the circuit would represent an error of only 4 yards. But with a scale factor of 1 volt per 12,000 yards, a millivolt (average) of noise would cause an error of 12 yards. Thus with a small scale factor, a given amount of noise represents a greater error.

On the other hand, if a very large scale factor, such as 1 volt per yard, is used, the problem of handling large voltages is encountered. If the computer had to handle 100,000 yards, the amplifiers and power sources would have to handle and supply 100,000 volts. This is nearly impossible.

Transistors, because of their low noise levels, are used extensively in computers. Small scale factors of 1 volt to 8,000 or more yards are common in transistorized analog computers.

SCALE FACTOR ANALYSIS

You must have a clear concept of scale factors, analog units, equation units, and their relationship to each other. This is a necessity when working with analog computers and understanding equipment OPs.

Given: The maximum range of a computer is 240,000 yards; the maximum voltage that the amplifiers can handle is 12 volts. The scale factor is then equal to

$$\text{scale factor} = \frac{\text{analog units}}{\text{equation units}}$$

$$\text{scale factor} = \frac{12\text{ V}}{240{,}000\text{ yd}}$$

$$\text{scale factor} = \frac{1\text{ V}}{20{,}000\text{ yd}}$$

This scale factor states that 1 volt is equal to, or represents, 20,000 yards.

If the scale factor and the analog units are known, the equation units may be found in the following manner (assuming an analog voltage of 3 volts).

$$\text{equation units} = \frac{\text{analog units}}{\text{scale factor}}$$

$$\text{equation units} = 3\text{ volts}/\frac{1\text{ V}}{20{,}000\text{ yd}}$$

$$\text{equation units} = 3 \times \frac{20{,}000\text{ yd}}{1} = 60{,}000\text{ yd}$$

If the scale factor and the equation units are known, the analog units may be found using the following formula.

$$\text{analog units} = \text{equation units} \times \text{scale factor}$$

$$\text{analog units} = 60{,}000\text{ yd} \times \frac{1\text{ V}}{20{,}000\text{ yd}}$$

$$\text{analog units} = 3 \times 1\text{ V} = 3\text{ V}$$

In the maintenance of a computer, it is sometimes necessary to perform the above computations to check the scale factor, the accuracy of the analog voltage, and the overall accuracy of the computation. For some computers, the scale factor is listed at the top of each column for the various computing accuracy tests performed on the computer. For other computers, it is necessary to use the computer prints to obtain the scale factor. In many instances, the scale factor is expressed as a ratio of equation units to analog units; for example, 90,000 yards per volt, 6,000 yards per revolution. Do not let this confuse you. Both methods are accepted forms of expressing scale factors. However, when the scale factor is expressed in a ratio of equation units to analog units (yards per volt), the smaller the scale factor, the greater is the accuracy.

BASIC COMPUTING ELEMENTS

The computing elements can be divided into three major groups by the method they use to solve a mathematical problem–MECHANICAL, using angular rotations of shafts, and linear movement of shafts and linkages; ELECTROMECHANICAL, using voltages and shaft positions; and ELECTRICAL, using voltages and current. Fundamentally, however, computing elements that perform the same mathematical function operate in a similar manner. Remember that the computing methods and elements presented here are basic. You will find many variations of these methods in the actual equipment.

MECHANICAL COMPUTING ELEMENTS

Before we discuss mechanical computing elements, you should be made aware that these devices are rapidly becoming a rare breed in the computer families. They are being replaced by electromechanical or electronic devices. The reason for discussing them in this chapter is to aid you in understanding how a mechanism can be manipulated to solve a mathematical problem. As was said earlier in this chapter, computing elements that perform the same mathematical function operate in a similar manner. Therefore, mechanical computing elements will give you an additional boost in your learning of how the basic computing elements function.

MECHANICAL SUMMATION DEVICES

Mechanical summation devices are of two basic types–those that use rotary gearing in an arrangement called a differential, and those that use linkages with linear movement.

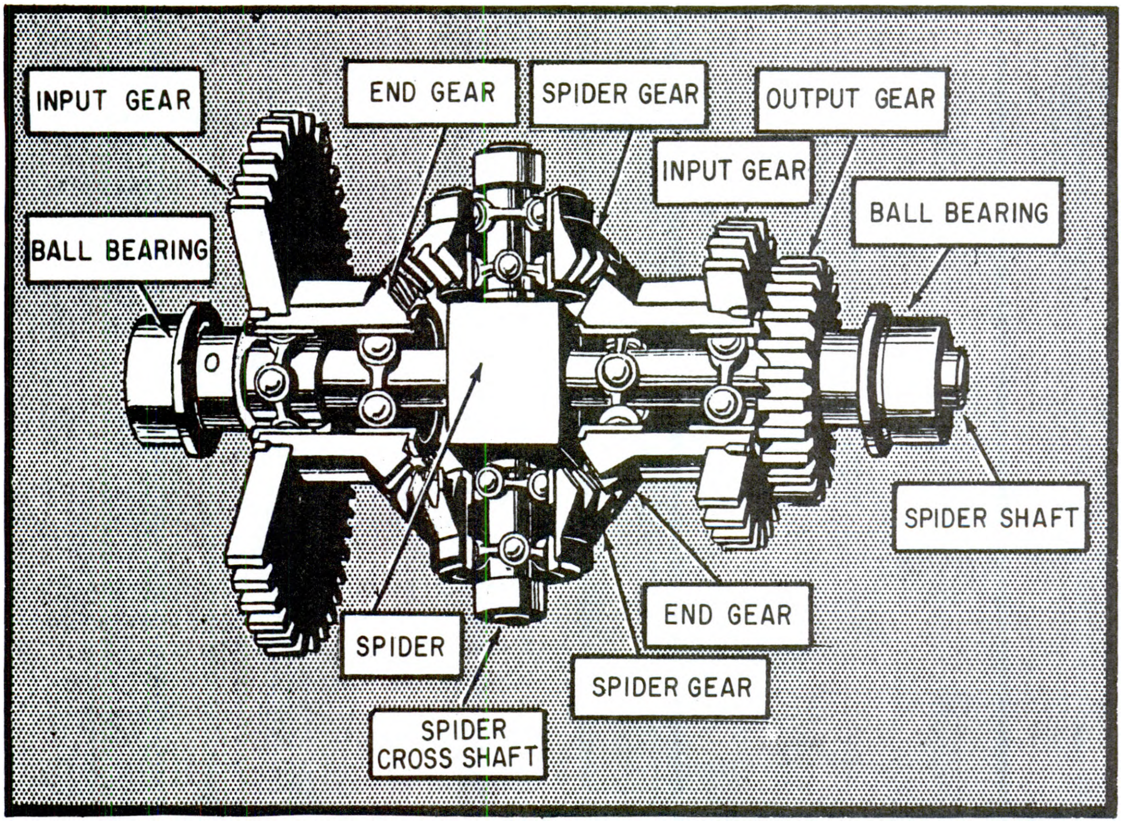
The differential is a mechanical summation device employed in rotary gearing type computers. The differential adds the revolutions of two shafts, or subtracts the revolutions of one shaft from those of another, and delivers the answer by positioning a third shaft. Differentials are divided into types by the gearing they use; bevel, spur, and planetary. Fundamentally, all operate in the same way. The bevel gear differential is by far the most common.

A cutaway view of a bevel gear differential is shown in figure 6-3. Grouped around the center of the mechanism are four bevel gears, meshed together. The two bevel gears on either side are called end gears, and the two bevel gears above and below are called spider gears. The spider gears are meshed with the end gears. The cross shaft and spider gears together are called the spider, and the long shaft is called the spider shaft. All four of the bevel gears are free to rotate on precision bearings. The three spur gears are used to connect the two end gears and the spider shaft to other mechanisms. They may be of any convenient size, and any one of them can be either an input or an output.

In operation, the end gears which are fixed to the input gears drive the spider gears. The spider (or inner) gears "walk" around the end gear faces to turn the spider assembly and shaft. Rotation of the spider rotates the output gear, which is pinned to the spider shaft.

First, consider either input gear held stationary while the other input gear is turning. The one that is turning will drive the spider gears. As the spider gears turn, they roll on the stationary end gear surface (attached to the stationary input gear). This results in a rotary motion of the spider shaft. Now, consider both end gears rotating at equal speed but in opposite directions. The right end gear attempts to rotate the spider in one direction, while the left end gear tends to rotate it in the other direction. The result is that the spider gears turn without rotating the spider, and there is zero output. Mathematically, this is the same as subtracting two equal quantities.

Now, consider both end gears rotating in the same direction and at the same speed. In this problem two equal quantities are added. The



12.87

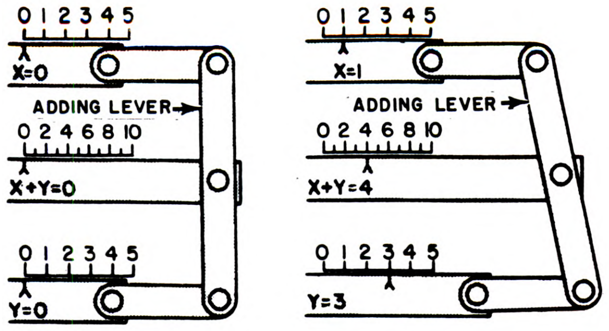
Figure 6-3.—Bevel gear differential.

resultant spider rotation will be PROPORTIONAL to the speed of either end gear, but the spider output will not be the sum of the two inputs. Actually, the spider makes only HALF as many revolutions as the sum (or difference) of the revolutions of the end gears. The output must be multiplied by two to give the correct answer. This can be done easily by appropriate gearing in the output train.

The input and output points need not be the same as those shown in figure 6-3. For example, the spur gear on the spider shaft could be used as one input, and one of the other spur gears as the second input. The remaining spur gear would then become the output. Thus any differential can be used in any of three ways, depending on which gear is used as the output.

Addition of two quantities is performed in the linkage mechanism by means of adding levers as shown in figure 6-4. In the example, two quantities, designated X and Y, are to be added. Their values are represented by the movements of the two slide bars. The adding lever is pivoted at its center to another slide bar, and its opposite ends are connected through links to the X and Y slides. To illustrate the problem, scales showing the values of the quantities represented by movements of slides have been drawn in the figure, and index marks are placed on the slides. The units on the center scale are half as large as those on the other two.

If the Y slide is held in place and the X slide is moved, the adding lever pivots about its lower end. The center slide, which is connected to the midpoint of the lever, then moves half as far as the X slide. If the X movement is one unit, the center slide also moves one unit, since the units



12.88

Figure 6-4.–Adding lever.

on the center scale are half as large as those on the X scale. Similarly, movements of the Y slide with the X slide held in place add one unit on the center scale for each unit movement of Y. At the left of figure 6-4, the parts are shown in zero position, with the three index marks opposite the zero points of the scales. At the right, the X slide has been moved one unit, and the Y slide has been moved three.

The center slide has traveled one unit in response to the X travel and three more in response to the Y travel, and so stands at a reading of four. Similarly, for any position of the X and Y slides, the reading on the center scale represents the quantity X plus Y.

There are several variations of the adding lever used in computing linkage, but their operating principles are the same.

MULTIPLICATION

There are two basic types of mechanical multipliers–those using rotary gearing and those using linkages.

Rotary Gearing Multipliers

The rotary gearing multipliers produce a solution through the use of similar triangles. There are four types of rotary gearing multipliers–screw, rack, sector, and cam. Since they all operate in fundamentally the same manner, we will discuss the screw type multiplier.

The screw type multiplier, shown in figure 6-5, has two inputs and one output. The inputs are shaft values which position the input slide and input rack. The output appears at the output rack which positions the output shaft. Thus, the output shaft value is always proportional to the product of the two inputs.

One input gearing is connected to two long screws. These screws pass through the threaded sleeve-like ends of the slotted input slide. As the input gears to the screws are rotated, the two screws turn to move the slide to the left or right. At the same time, the other input moves the input rack up or down, moving the slotted pivot arm around the stationary pin.

The multiplier pin is mounted in the slots of the input slide, pivot arms, and output rack, connecting all three where the slots cross. As the multiplier pin moves with the input slide and pivot arm, it positions the output rack and gear.

Now, consider the multiplier in the zero position shown in figure 6-6. If only the screws are rotated, the input slide moves to the right; but it will not affect the output rack. Similarly, if only the input rack is moved up or down from the zero position, the output rack will be unaffected. This is a reasonable result, for any number multiplied by zero is equal to zero.

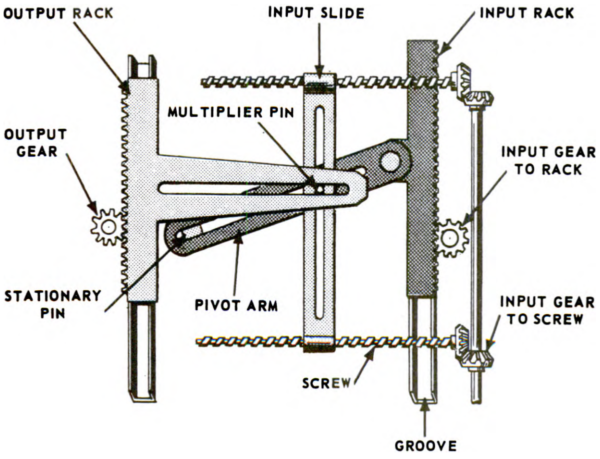


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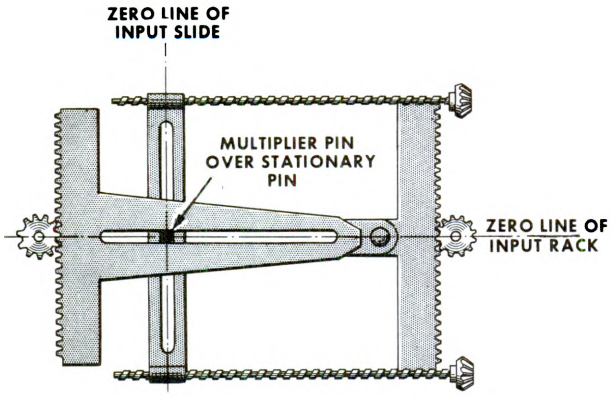
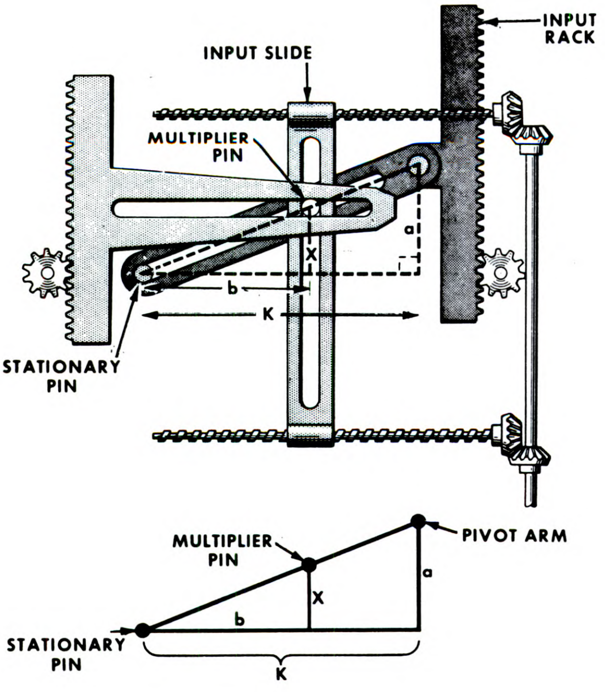
Figure 6-5.–Screw type multiplier.



12.92
Figure 6-6.—Screw type multiplier—zero position.

From this we can conclude that both inputs must be removed from the zero position for an output. Such a condition is shown in figure 6-7. Notice the triangle superimposed on the device. The value a represents the amount of rack input. The value b represents the amount of slide input. K is a fixed distance, since the multiplier pin cannot move and the input rack travels in a machined guide rail.



12.93
Figure 6-7.—Screw type multiplier—multiplying positive values.

Because the angles in the superimposed triangle and the one shown below the figure are equal, the triangles are similar. Thus the value of X can be determined if the other values are known.

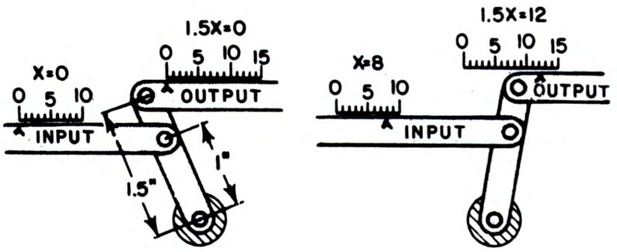
$$X = \frac{ba}{K}$$

This equation shows that the output, X, is always proportional to the product of the two inputs. The constant value, K, can be compensated for by the proper choice of input and output gearing for the multiplier. These multipliers can also determine the product of negative values.

Linkage Multipliers

Linkage multipliers of the type described here are used when one of the factors is a constant, as shown in figure 6-8. In this example, we want to transform a movement representing the quantity X into one representing 1.5X. One end of the multiplying lever is pivoted on the fixed frame of the computer, as indicated by the cross-hatched circle in the figure.

The input and output links are connected to the lever at different points, the connection of the output link being 1.5 times as far from the fixed pivot as the connection of the input link. The two scales shown in figure 6-8 have units of

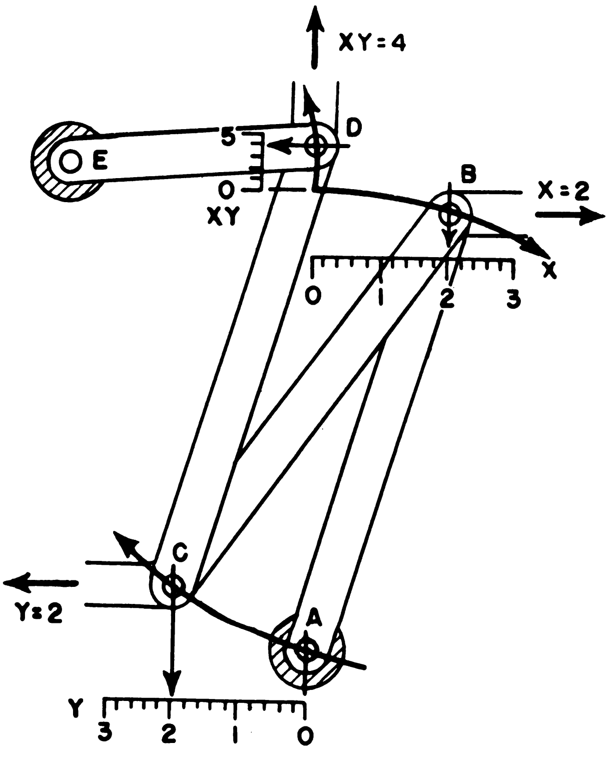


12.98
Figure 6-8.—Multiplying lever.

the same size; but because of the difference in lever arms, each one-unit movement of the input link moves the output link in a unit and a half. Then, if the input movement represents the quantity X, the output represents 1.5X.

In many cases the computing problem requires the multiplication of two variable quantities. The multiplying levers shown in figure 6-8 cannot be used for this purpose.

Figure 6-9 shows a linkage designed to multiply two variables, X and Y. The levers AB and ED are pivoted on the fixed structure and are connected by links BC and CD, both of which have exactly the same length as AB. The X input is applied by a link connected at B. The Y input is applied by a link connected at C; and the output XY is taken off at D. In the position of the links shown in figure 6-9, X equals two units, Y equals two units, and XY equals four.



12.99

Figure 6-9.—Multiplying linkage.

This type of linkage in the computer can be operated in reverse to serve as a divider instead of a multiplier. Two inputs are applied at the points corresponding to B and D in figure 6-9. The output taken off at C then represents the input at D divided by the input at B.

DIVISION

Division problems are generally difficult for a computer to perform. Multiplication is the inverse of division. When possible, the problem is rearranged so that it becomes a problem in multiplication.

As an example, let's say that we wanted to divide two variables. If the divisor is 2 and the dividend is 10, we know that the quotient is 5.

$$\text{divisor} = 2\ /\frac{5 = \text{quotient}}{10 = \text{dividend}}$$

If the reciprocal $(\frac{1}{X})$ of the divisor (.5) is used, and multiplied with the dividend (10), it will produce the same answer as the quotient (5).

$$.5 \times 10 = 5$$

So, all that is needed to perform division by the process of multiplication is a device that will produce a reciprocal output of an input quantity. Reciprocal devices are used in analog computers, and will be discussed later in this chapter.

NONLINEAR FUNCTIONS

In this section we will discuss the instrumentation of mathematical operations such as raising a term to a power, taking the reciprocal of a number, and generating trigonometric functions.

Cams

Cams are devices which produce a mechanical output that has a nonlinear relation with its input. A cam converts mechanical motion from angular to linear, or vice versa. The output motion is related to the input by the shape or cut of the cam. Thus, depending on how the cam is cut, the output is some function of the input. Cams are cut to trigonometric, exponential, reciprocal, and empirical functions. An empirical function is one in which the factors cannot be correlated through normal mathematical methods.

A basic cam is shown in figure 6-10. The cam has some kind of curved surface, such as a groove. The groove is positioned by the input gear, which rotates the cam. The cam also has some device like a roller or a ball, called a follower, which bears against the groove. At any given position of the cam, the follower is pushed by the groove into a position which registers the output gear value for that point of contact.

SQUARING CAM.—A cam can be used as a mechanical means of raising a term to a power. However, its use is normally limited to squaring a term. Figure 6-11 illustrates a basic square cam and two types of followers used to transmit outputs to other devices. The input positions the cam as indicated by the numbers around the outside of the cam. The follower then registers the output value in accordance with its position in the groove or on the curved surface. The output of a square cam will always be a positive value.

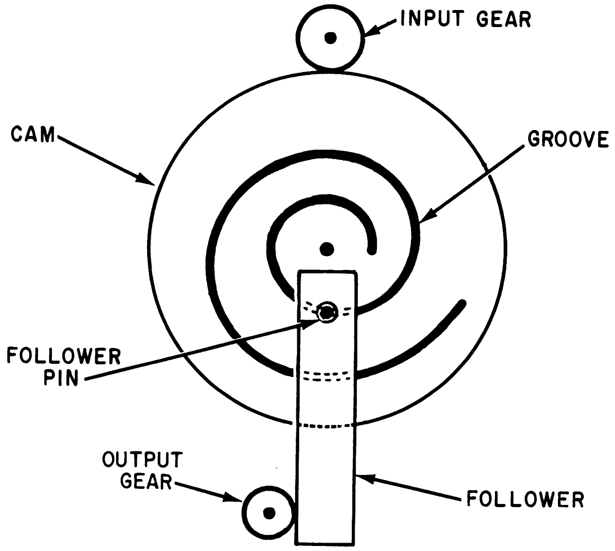


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Figure 6-10.—A typical cam.

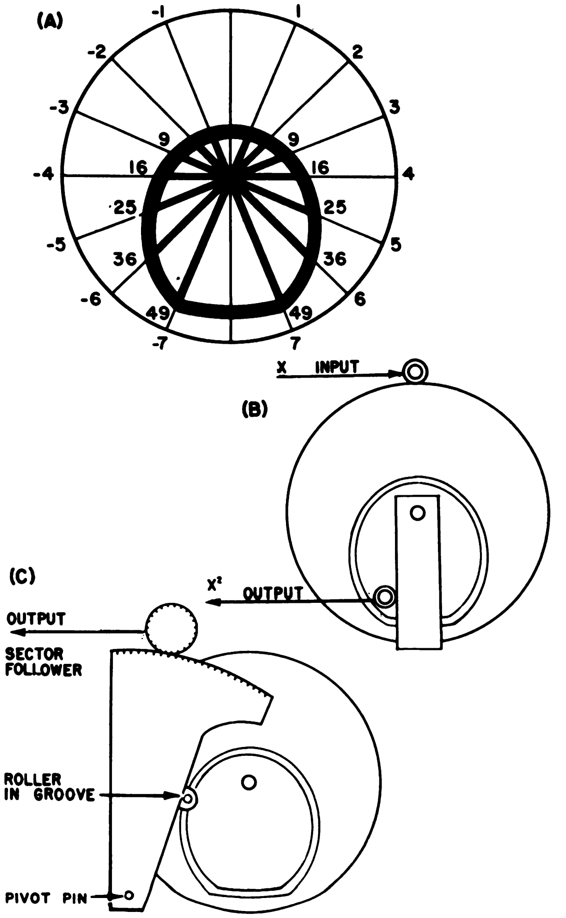

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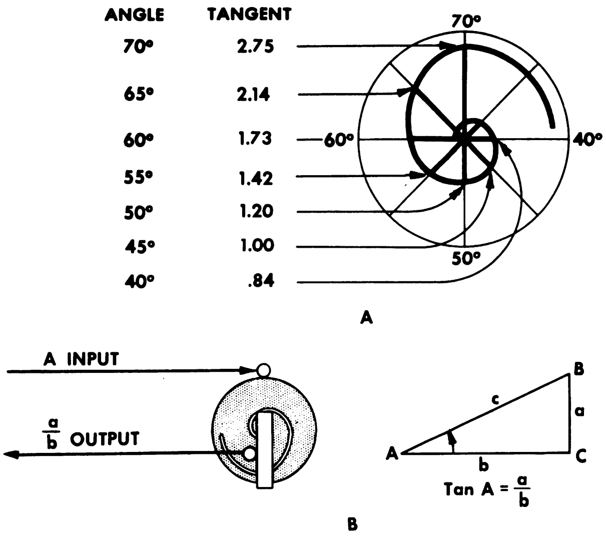
Figure 6-11.—Squaring cam.

TANGENT CAM.—The tangent cam is used to produce a trigonometric function. Its operation is limited to angles below 90°; this is because the tangent function of a varying angle approaches infinity as the angle approaches 90°. The tangent cam (fig. 6-12) does not differ greatly from any other cam, except that the groove is cut differently.

RECIPROCAL CAM.—As was stated earlier, one of the easiest ways to divide one number by

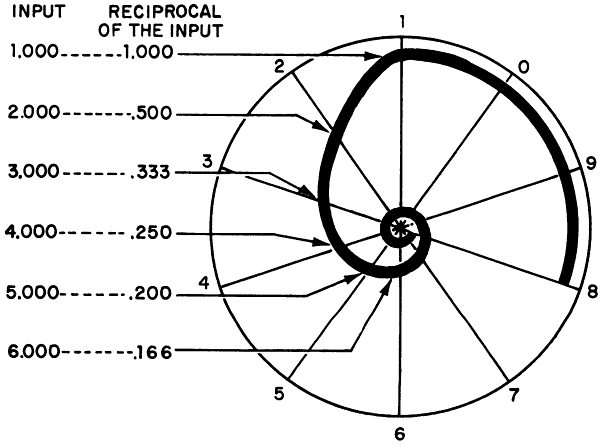


12.116

Figure 6-12.—Tangent cam.

another (mechanically) is to multiply the first number by the reciprocal of the second number.

In figure 6-13, to get the reciprocal of a number, the cam is turned to the position corresponding to that number. The output pin on a follower will then be a distance from the center corresponding to the reciprocal of the number.



166.226

Figure 6-13.—Reciprocal cam.

The number goes in; and out comes the reciprocal.

BALLISTIC CAMS.—Ballistic cams in a computer are cut to represent empirical functions. An empirical function is one in which the factors cannot be correlated through normal mathematical methods. The function between the related factors is determined by experiments and measurements. Frequently, however, the desired quantity is a function of two factors. In this case a barrel or two-dimensional cam is used. A barrel cam is actually a group of cams consolidated into a single piece (fig. 6-14). In the figure, the cam's output is proportional to superelevation, which varies with elevation and range. Elevation drives the cam follower along the guide rod to the correct portion of the cam for that elevation. Range rotates the cam to the correct position. The output is therefore a function of both range and elevation.

Component Solver

A component solver takes a vector of a given magnitude and angular position, and resolves it into its two rectangular components. There are several types of component solvers. However, this discussion will be limited to the screw type component solver.

The screw type component solver, figure 6-15, consists of a vector gear, two racks, two output gears, two input gears, and a screw and pin assembly.

The speed input gear drives a gear train which causes the screw to turn. As the screw turns, it drives an assembly carrying the pin, thus changing the length of the vector which is proportional to the input component, such as range.

In this type of component solver, the pin can travel nearly the full width of the vector gear. From the pin's zero or center position, it

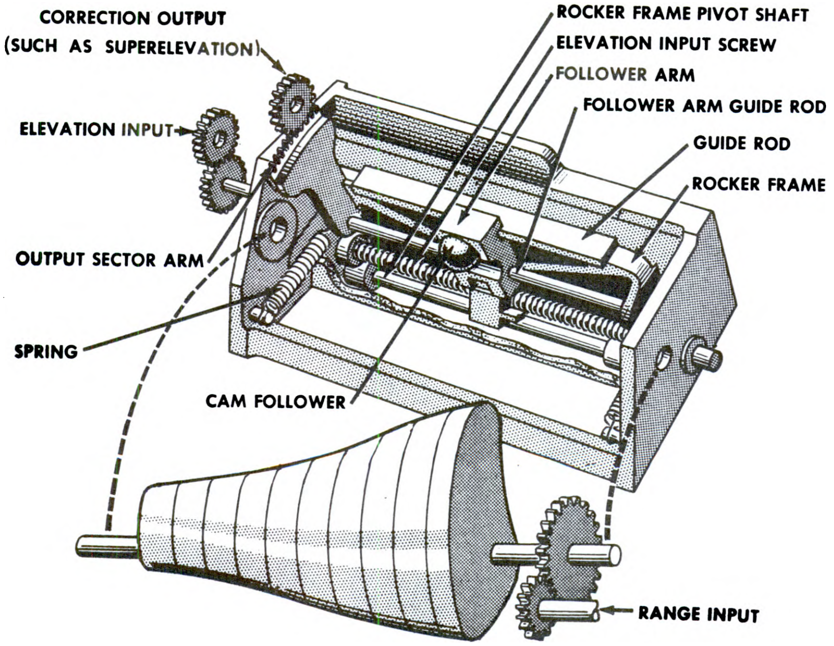


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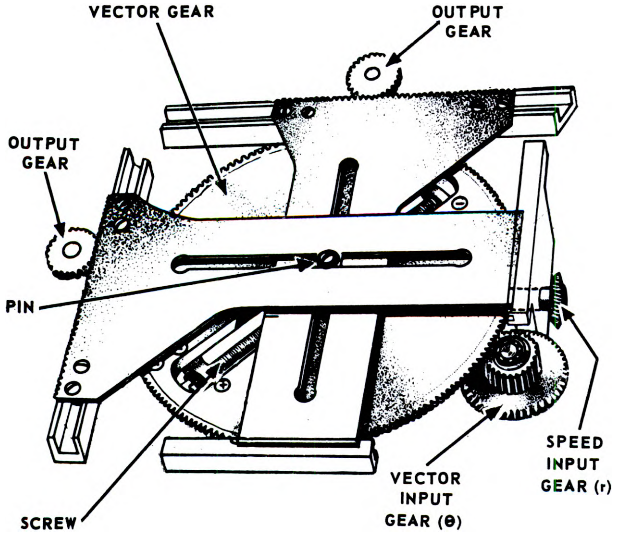
Figure 6-14.—Barrel cam.



12.113

Figure 6-15.—Screw type component solver.

can be moved in either of two directions, which correspond to positive or negative.

The vector input gear drives the vector gear in the desired angular direction, indicating target position θ. The pin positions the racks as it moves along the slot, thus resolving the vector into its components. Therefore, the component solver solves for the desired quantities, as shown in figure 6-16.

Angle Resolver

An angle resolver is a linkage mechanism which computes the sine and cosine of an angle. Figure 6-17A shows an angle resolver consisting of gear H with two crank pins M and N. They are mounted 90° apart and equidistant from the center of the gear. Attached to each crank pin is an output link which transmits the horizontal component of motion of the pin as the gear rotates. The horizontal component of the displacement of pin M is proportional to the sine

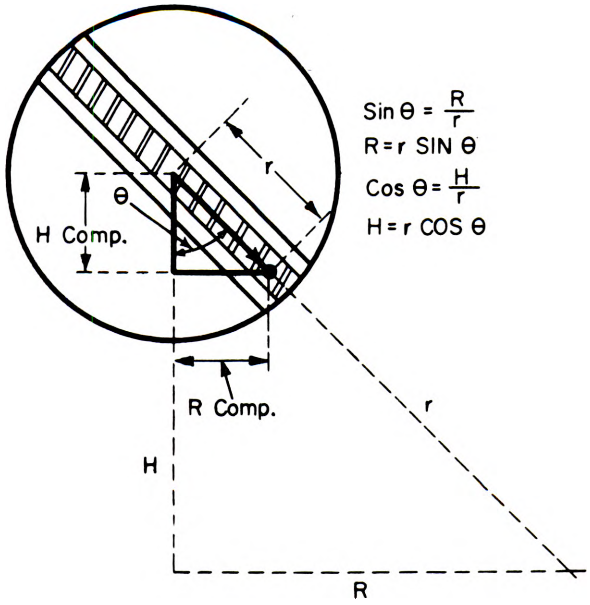


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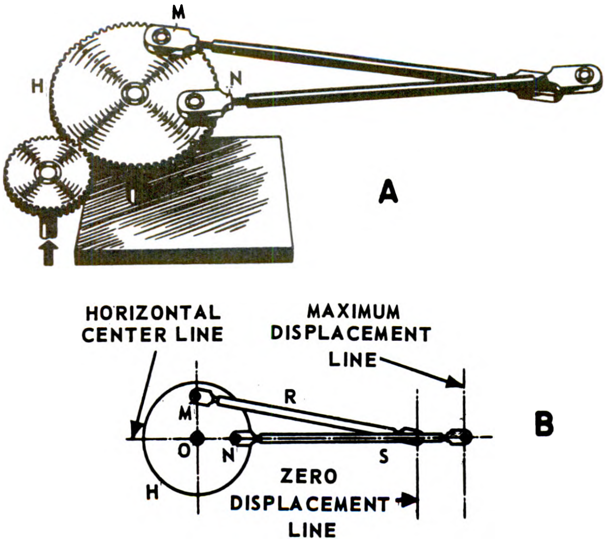
Figure 6-16.—Problem solution using a component solver.



12.115

Figure 6-17.—Basic linkage angle resolver.

of the angle through which gear H rotates. The horizontal component of pin N is proportional to the cosine of the angle through which gear H rotates.

Figure 6-17B shows the resolver in its zero position, with the radius OM perpendicular to the horizontal center line and the radius ON in the horizontal center line. Notice that link R (sine output) is at zero horizontal displacement, and that link S (cosine output) is at maximum horizontal displacement. If gear H is rotated clockwise through an angle of 30°, link R will move to the right and link S to the left along the horizontal center line. The linear displacement of the output links will be proportional to the sine and cosine function of the angle.

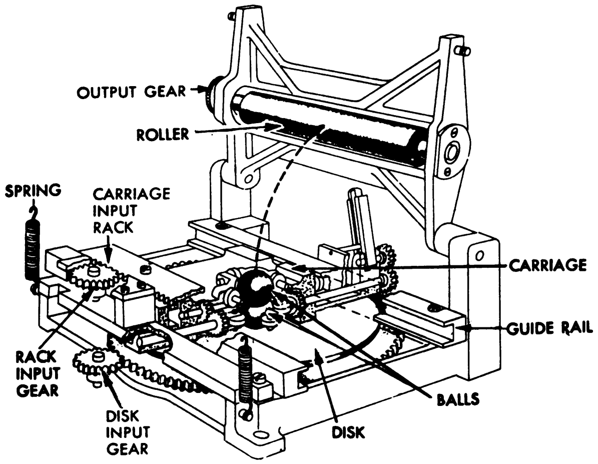
The outputs of the resolver of figure 6-17 are only approximate values. This is because the output links are not parallel to the horizontal center line. The output links have a slight angular movement that must be compensated for to eliminate distortion. This is accomplished by additional gearing, and by making the pins M and N eccentric.

INTEGRATION

Integration is the process of determining the change which will occur over a period of time in the value of a variable quantity which is changing at a known rate. Hence integration consists of the summing up of all the minute changes in a quantity, to find the total amount of change which took place. Since integration in the solution of the fire control problem is usually the summing of changes in a quantity with respect to time, it is a continuous process.

The change of range for a constant range rate may be computed by multiplying the rate at which range is changing by the length of time of the problem. Hence if the rates in fire control were constant, a simple mechanism would produce the desired output. Under actual conditions, however, the rates vary over a large scale. Therefore, a more complicated system must be used.

The ball-disk-roller type integrator (fig. 6-18) is used in mechanical fire control computers. The integrator disk is mounted on a gear and is turned directly by the input gear. The two balls, one on top of the other, are held in position

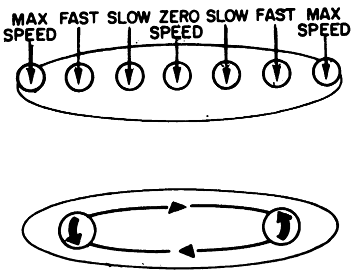


12.303

Figure 6-18.—Ball-disk-roller integrator.

between the disk and the output roller by the carriage assembly. The carriage is movable, and can position the balls along a straight line from one edge of the disk, through the center, to the other edge. The pressure needed to hold the balls against one another, and against the disk and roller, comes from a spring assembly. The motion of the disk is transferred through the balls to the roller by friction.

The mechanical operation of the integrator can be visualized (fig. 6-19). The circumference of the circle passing under the balls is greater when the balls are near the edge of the disk, and smaller when they are near the center. At the exact center of the disk, no motion is transferred to the balls. The balls will turn in one direction when they are on one side of the center of the disk, and in the opposite direction when they are on the other side. Hence the integrator acts as a reversible, variable gear ratio between the input to the disk and the output from the roller. The ratio is changed by the input to the carriage.



12.304

Figure 6-19.—Integrator operation.

Let's look at a practical application as found in a computer.

When the target is picked up, the initial range is set into the range system. At that moment, the time motor is turned on, setting the disk in motion. The rotating disk, then, can be compared to a clock which is constantly ticking away the passage of time from the instant the target is first sighted. In the range problem the disk always rotates in the same direction at a constant speed. This is a mechanical way of saying that time, which the disk represents, always goes by and never backs up.

Range rate is fed from the range rate system into the carriage input gear, which positions the carriage and the balls according to this rate. If the range rate is fast, the carriage will locate the balls away from the center, near one edge of the disk. If the rate is slow, it will locate them near the center of the disk. The speed of the balls depends on their distance from the center of the disk, so the speed of the balls is always proportional to the range rate.

The output roller is constantly being turned by the balls, with the roller's speed determined by the speed of the balls. The position of the roller at any moment (that is, the number of revolutions it has made from its initial position) tells the actual change in range during the time the disk has been turning. The output roller is geared to the range dial through a differential (summation device) so that this change in range is constantly being added to the initial setting to give present range at any moment.

ELECTROMECHANICAL COMPUTING ELEMENTS

An electromechanical computing element is one that has electrical parts as well as moving parts. Such basic elements as synchros, potentiometers, resolvers, and a.c. and d.c. generators are included in this category. Since the application of all these devices is a universal feature in Navy analog computers, these devices will be covered here in more detail to give you a solid background in how they work.

In an analog computer, these elements perform mathematical operations. The elements are then interconnected to solve equations. In each electromechanical computing element and throughout the computer, the physical quantity (the computer variable) represents, or is analogous to, the problem variable.

In a computer using electromechanical computation there are two types of analog variables: voltages and mechanical displacement (shaft revolutions). These variables represent such physical variables as range, elevation, bearing, speed, and initial velocity. Voltages, rather than currents, are used almost exclusively as the computing variable in modern analog computers using electrical computation. This is because voltages can be measured and recorded at any point in the circuit without disturbing (opening) the circuit. Therefore, electromechanical computing elements convert mechanical displacements into voltages, and appropriate scale factors are assigned to these voltages.

POTENTIOMETERS

Potentiometers, are the basic components used in analog computers to convert shaft positions to electrical voltages. In this conversion, the potentiometer actually multiplies a constant input voltage by the mechanical position of the slider. Potentiometers are used extensively to multiply, divide, and generate nonlinear functions (sine, cosine, secant, etc.).

A potentiometer, shown schematically in figure 6-20A, is a resistance element having terminals at each end and a sliding contact. The contact traverses the element from one end to the other, varying the resistance between the sliding contact and one of the fixed terminals.

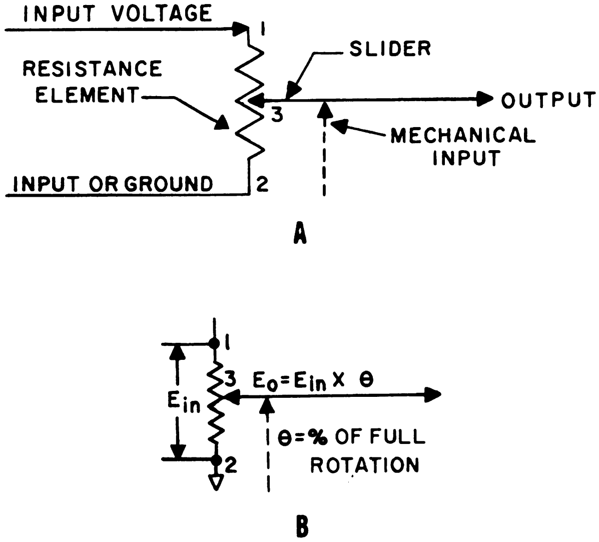


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Figure 6-20.—A. Potentiometer schematic; B. Volts χ motion multiplication.

Each terminal and the slider are numbered; the slider usually has the higher number. The resistance element of a precision potentiometer is wire wound because wire has a lower noise level than carbon compound or similar mixture.

The resistance element is wound on a core called a mandrel, the shape of which depends on the design and function of the potentiometer. For a linear one-turn potentiometer, the wire is evenly spaced on the mandrel, which is then shaped to form a circle. This permits the slider to move mechanically through 360° of rotation; thus, the electrical resistance between the slider and one end of the potentiometer varies directly with the mechanical position of the slider. For a linear 10-turn potentiometer, the wire is usually wound on a rod which is then shaped to form a helix, or spiral. This allows the slider to rotate as many as 10 full revolutions.

Types of Potentiometers

There are two types of potentiometers used in analog computers: linear and nonlinear. A linear potentiometer has its resistance element distributed evenly about its mandrel, so that each turn has the same amount of resistance. As the input shaft is rotated, the slider touches various windings and causes a change in resistance between the slider and the ends of the potentiometer. With the potentiometer energized, the voltage output varies linearly as the slider is moved from end to end, because the voltage drop across each turn is the same.

A nonlinear potentiometer is one whose voltage output does not vary at a constant rate as the slider moves. Nonlinear potentiometers are sometimes referred to as shaped or tapered potentiometers because the resistance element is wound on specially shaped mandrels, each turn having a different length of wire. Thus, the total resistance is distributed unevenly throughout the length of the potentiometer. With the potentiometer energized, the voltage output will vary in a nonlinear fashion as the slider is moved from one end to the other. Nonlinear potentiometers can be constructed to produce practically any of the nonlinear functions present in the fire control problem.

Representing Computing Variables Electrically

A potentiometer can also be thought of as a variable voltage source rather than a variable resistor, since the input voltage is applied to the resistance element and a fraction of the voltage appears as the output between the slider and one of the potentiometers. When the input voltage is constant, the potentiometer converts a mechanical input quantity into an electrical quantity. Thus any computer variable can be represented electrically by using a potentiometer to make the mechanical to electrical conversion.

Here, the potentiometer actually multiplies a voltage by a motion (slider position). The input voltages, E_{in}, is impressed across the resistance element through terminals 1 and 2. (See fig. 6-20B.) The mechanical input, θ (THETA), is a percentage of full rotation of the slider. If the input voltage is 30 volts and the slider is positioned at 100-percent full rotation, then

$$E_o = 30 \text{ volts} \times (1.0) = 30 \text{ volts}$$

When θ is at 25-percent full rotation, only one-fourth of the input voltage occurs at the slider.

$$E_o = 30 \text{ volts} \times .25 = 7.5 \text{ volts}$$

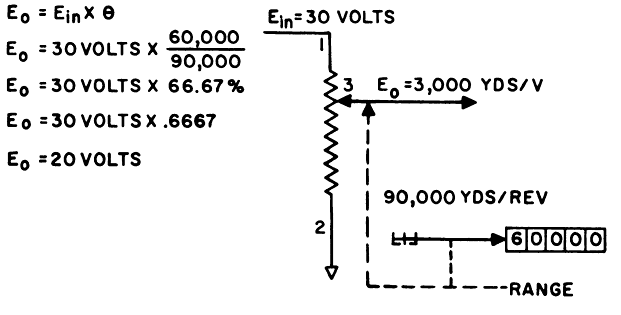
If θ is at 50 percent of full rotation, only one-half of the input voltage occurs at the slider.

$$E_o = 30 \text{ volts} \times .5 = 15 \text{ volts}$$

When a suitable scale factor is assigned to the mechanical input, the output can represent any computer variable electrically. For example, assume that a one-turn potentiometer is used to represent a maximum range of 90,000 yards in a computer. For one full revolution of mechanical input, the slider will move from terminal 2 to terminal 1. This amount of motion represents a range of 90,000 yards. The maximum range, or any fraction thereof, can be represented electrically by positioning the slider between terminals 2 and 1.

When a range counter indicates 60,000 yards, as shown in figure 6-21, the slider has moved through 66.67 percent of its travel from terminal 2, and 20 volts will appear as the output at terminal 3. Thus by the multiplying feature of the potentiometer (volt χ motion), range, represented by a shaft position and indicated by a counter, has been converted into an electrical voltage.

In addition to the mechanical scale factor assigned to a potentiometer, an electrical scale factor is also assigned to the output voltage. The


$E_o = E_{in} \times \theta$
$E_o = 30 \text{ VOLTS} \times \frac{60,000}{90,000}$
$E_o = 30 \text{ VOLTS} \times 66.67\%$
$E_o = 30 \text{ VOLTS} \times .6667$
$E_o = 20 \text{ VOLTS}$
$E_{in} = 30$ VOLTS
1
3
$E_o = 3,000$ YDS/V
90,000 YDS/REV
2
60000
RANGE

167.62

Figure 6-21.—Potentiometer used to represent range electrically (360° rotation).

electrical scale factor is the yards per volt ratio. For the problem illustrated, the yards per volt ratio equals

$$\frac{yd/r}{V/r}, \text{ or } \frac{90{,}000\text{ yd}}{30\text{ V}}$$

Thus, the yards per volt ratio is 3,000 yards per volt. This indicates that each volt which appears at the slider represents 3,000 yards of range. Therefore, if 20 volts is measured at the output, and each volt represents 3,000 yards of range, then

$$E_o = 20\text{ V} \chi 3{,}000\text{ yd/V} = 60{,}000\text{ yd}$$

Another scale factor pertaining to the potentiometer can be very useful in determining how many yards an output voltage represents. This scale factor is the ratio of the volts per revolution to the yards per revolution. For the problem illustrated, the volts per yards ratio equals

$$\frac{V/r}{yd/r}, \text{ or } \frac{30\text{ V}}{90{,}000\text{ yd}}$$

Thus, the volts per yard ratio is .000333. This scale factor indicates that for each yard inserted into the potentiometer mechanically there will be .000333 volt available at the output. Thus, if the output voltage were 6.666 volts, the number of yards this voltage represents can be determined in the following manner.

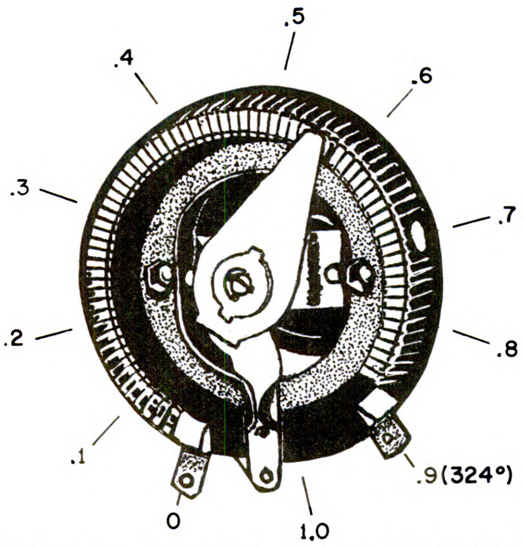
$$\text{equation units} = \frac{\text{analog units}}{\text{scale factor}}$$

$$\text{range in yards} = \frac{6.666}{.000333}$$

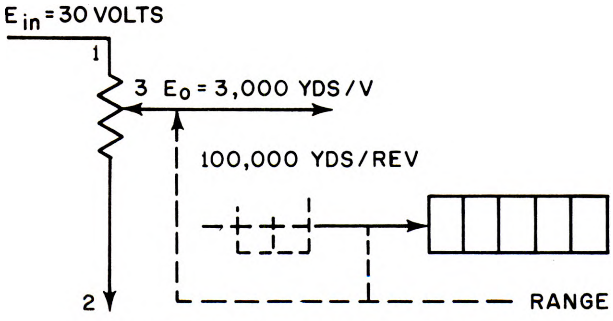
$$\text{range in yards} = 20{,}018$$

When computing how many yards an output voltage represents, it is more convenient to use the scale factors of a potentiometer rather than the percentage of full rotation of the slider. This is true because many one-turn potentiometers actually do not rotate a full revolution. Furthermore, many 10-turn potentiometers rotate only 9.6 revolutions instead of 10 full revolutions. If the potentiometer shown in figure 6-22 is used to represent a maximum range of 90,000 yards electrically, the scale factors assigned indicate that the potentiometer does not rotate a full revolution. If the total yards represented electrically (total yards = applied voltage χ electrical scale factor) and the mechanical scale factor are not the same, then the potentiometer does not rotate a full revolution.

In this problem the mechanical scale factor indicates that one full revolution of the slider



A. MECHANICAL INPUT = DIAL READING X 100,000 YDS



B. ELECTRICAL REPRESENTATION OF (A)

167.63

Figure 6-22.–Potentiometer used to represent range electrically (324° rotation).

Table 6-1.—Volts per revolution, yards per volts, and volts per yard ratios

RATIO	90,000 YDS/REV POT	100,000 YDS/REV POT
Volts/Rev	$\frac{30 \text{ volts}}{1 \text{ rev}} = 30$ volts/rev	$\frac{30 \text{ volts}}{.9 \text{ rev}} = 33.333$ volts/rev
Yards/Volt	$\frac{90{,}000}{30} = 3{,}000$ yards/volt	$\frac{100{,}000}{33.333} = 3{,}000$ yards/volt
Volts/Yard	$\frac{30}{90{,}000} = .000333$ volt/yard	$\frac{33.333}{100{,}000} = .000333$ volt/yard

167.746

represents 100,000 yards of range. The electrical scale factor and the applied voltage indicate that the maximum range represented electrically is 90,000 yards (30 volts χ 3,000 yards per volt). Therefore, a ratio exists between the total yards represented electrically and the yards per revolution. Thus, total revolutions of the potentiometer are equal to

$$\frac{\text{total yd,}}{\text{yd/r}} \text{ or } \frac{90{,}000}{100{,}000} = 0.9 \text{ r}$$

Thus, the potentiometer will actually rotate 324° (360 χ 0.9) to represent 90,000 yards of range.

What effect will this amount of rotation have on the volts per revolution, yards per volt, and volt per yard ratios of the potentiometer? Each ratio is compared for both potentiometer to show which is affected.

You can see from table 6-1 that only the volts per revolution ratio is changed. The other ratios will not change because the electrical scale factor for each potentiometer is 3,000 yards per volt. However, if each potentiometer is rotated the same number of degrees, the percentage of full travel, the output voltage, and the number of yards represented electrically are different for the two potentiometers. In figure 6-23, each slider has been rotated 180° from terminal 2. The percentage of full travel, the output voltage, and the yards represented by each potentiometer are computed for a mechanical input of 180°.

Double-Ended Potentiometers

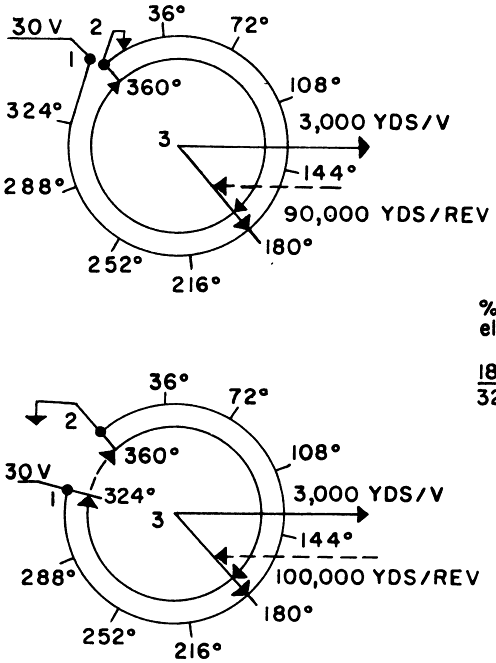
A potentiometer can be used to represent a computer variable that may be either plus or minus with respect to a zero reference. In this case, both ends of the potentiometer are energized, one with a plus voltage and the other with a negative voltage. The center of the potentiometer will represent the zero reference. The center may or may not be grounded.

When used this way, the potentiometer still multiplies a voltage by slider position. However, when the slider is at the center of the resistance element, the output voltage is zero. Therefore, the center of the potentiometer is the point of reference from which the percentage of rotation is measured. If the potentiometer is energized with +16 and -16 volt (as shown in fig. 6-24) and the slider is positioned one-quarter of a revolution from the center (zero reference) of the potentiometer (this amount of slider travel is one-half of the available slider travel from the center to the end of the potentiometer), then the output voltage, E_0, is computed by multiplying the input voltage, 16 volts, by twice the percentage of rotation of the potentiometer. Therefore,

$$E_0 = 16 \chi 2(0.25) = 8 \text{ V}$$

The output voltage will be either plus or minus depending on the direction of slider movement from the reference point.

The potentiometer in figure 6-24 electrically represents a rate whose maximum limits are



% of full travel of slider on resistance element is:

$\frac{180°}{360°} = .50$ or 50%.

$E_0 = E_{in} \times \theta$

$E_0 = 30v \times .5$

$E_0 = 15$ volts

E_0 = in yards is:

15v x 3,000 Yds./V = 45,000 Yds.

% of full travel of slider on resistance element is:

$\frac{180°}{324°} = .55555$ or 55.555 %

$E_0 = E_{in} \times \theta$

$E_0 = 30v \times .55555$

$E_0 = 16.6665$ volts

E_0 in yards is:

16.6665 v x 3,000 Yds/V = 50,000 Yds.

167.64

Figure 6-23.—Comparison of potentiometer outputs.

+400 and -400 knots (kn); thus it is possible for the rate to change a total of 800 knots. The travel of the slider from one end to the other will represent 800 knots, and if a one-turn potentiometer is used the mechanical scale factor must be 800 knots per revolution. The difference in voltage between each end of the one-turn potentiometer is 32 volts, which represents 800 knots. Therefore, the following ratios can be written for the potentiometer.

$$V/r = 32\ V/r$$

$$kn/r = 800\ kn/r$$

$$kn/V = \frac{800\ kn/r}{32\ V/r} = 25\ kn/V$$

$$V/kn = \frac{32\ V/r}{800\ kn/r} = .04\ V/kn$$

If the slider is positioned to represent 200 knots, then the output voltage is determined as follows.

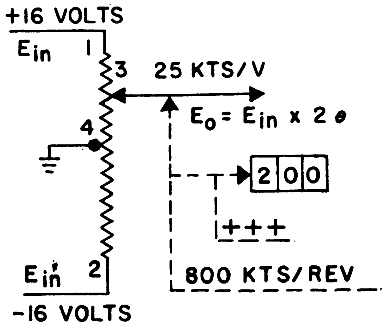
$$\text{equation units} \times \text{scale factor} = \text{analog units}$$

Thus,

$$200\ kn \times 0.04\ V/kn = 8\ V$$

Use of Multiturn Potentiometers

The choice of mechanical scale factors is very important when dealing with potentiometers. You have seen that the mechanical scale factor is always compatible with the physical limits of a potentiometer, and the electrical scale factor represents the mechanical input at all times. The use of multiturn potentiometers increases the accuracy



167.65
Figure 6-24.—Potentiometer representing a plus and minus rate.

of the mechanical input so that lost motion (number of degrees the slider is in error) will not cause too large an error in the output.

Illustrated in figure 6-25 are two potentiometers, used to represent 90,000 yards of range. The same electrical scale factor (3,000 yards per volt) is maintained for each. However, to increase the accuracy of the output per degree of error of the slider, one is a 10-turn potentiometer. Each potentiometer is energized by 30 volts. The slider of the 1-turn potentiometer will rotate 360° while the 10-turn slider will move through 3,600°. Table 6-2 can be used to compare the accuracy of the 1-turn to 10-turn potentiometers.

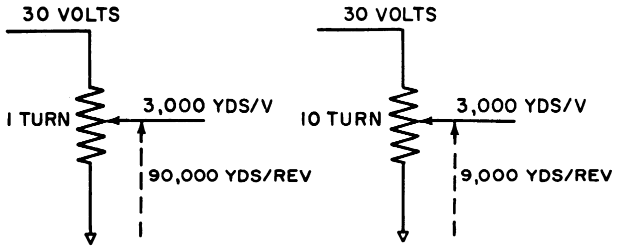


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Figure 6-25.—Using multiturn potentiometers to increase accuracy.

Sine and Cosine Potentiometers

A specially constructed potentiometer can be used to generate voltages proportional to the sine and cosine of a computer variable which appears as a mechanical rotation. This function generator is called a sine and cosine potentiometer.

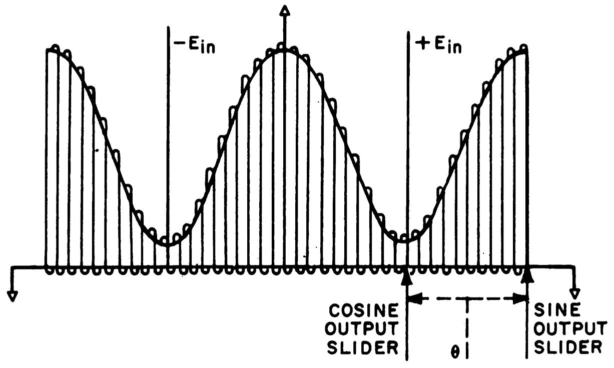
The shape of the potentiometer card (fig. 6-26), is made proportional to the cosine function, then the resistance element is wound in a continuous layer around the card. The ends of the card are then joined together, thus forming a cylinder with two lobes. The ends of the resistance element are joined together to provide for continuous rotation of the potentiometer shaft.

The high points, or lobes, of the cylinder are connected to ground. A positive voltage is connected to one of the low points and a negative voltage to the other. The sine and cosine outputs are obtained simultaneously by having two sliders 90° apart and connected mechanically as a single unit but electrically

Table 6-2.—One-turn to ten-turn potentiometer accuracy

	ONE-TURN POTENTIOMETER	TEN-TURN POTENTIOMETER
Total Travel	360 degrees	3,600 degrees
Yards/Volt	3,000	3,000
Yds/Degree	90,000 Yds/360° = 250	90,000 Yds/3,600° = 25
Volts/Degree	30 volts/360° = .08333	30 volts/3,600° = .008333
1° of error	.08333 volts or 250 yards	.008333 volts or 25 yards

167.747



55.3

Figure 6-26.—Sine and cosine potentiometer, cosine card type.

isolated from each other and the potentiometer shaft.

The potentiometer shaft is shown in its zero position. The sine output is zero volts because the slider is in contact with a grounded portion of the resistance element. The cosine output is a maximum plus voltage because the slider is in contact with the plus reference voltage. One full rotation of the shaft counterclockwise will reduce voltages that are proportional to the sine and cosine functions of the mechanical input. The polarity of the output voltages will be the same as the signs of the sine and cosine functions for all four quadrants.

RATE GENERATORS

A rate generator (tachometer) (fig. 6-27) puts out a voltage proportional to the magnetic field surrounding the motor and the speed of the rotor. In a rate generator the magnetic field is held constant but the speed of the rotor is variable. The amplitude or value of the output voltage is proportional to the velocity of the input signal (speed of rotation of the rotor).

Rate generators are used in computers to perform computations and as a source of stabilizing voltage for servoloops. This is changing mechanical information (speed) to electrical information.

The rate generator used in computers may be an a.c. or a d.c. generator. The d.c. generator uses a permanent magnet to produce the magnetic field. The a.c. generator is excited by an a.c. voltage which produces the magnetic field in which the rotor rotates. The flow of energy is from input winding, to rotor, to output winding. The output signal will be of the same frequency as the excitation voltage and is in phase or 180° out of phase with the input, depending on the direction of rotation. The a.c.

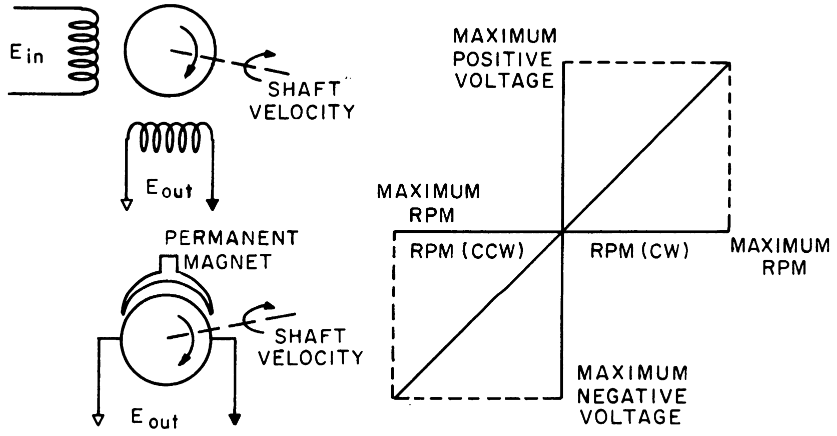


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Figure 6-27.—Output voltage versus rpms for a.c. and d.c. rate generators.

or d.c. rate generator will theoretically produce a zero output when the rotor is stationary and will produce an output voltage whose amplitude and linearity are proportional to rotor speed, up to the saturation limit.

In some computers the rotor of the a.c. rate generator is mechanically connected to the rotor of a servomotor. In other computers the rate generator and the servomotor are one unit; that is, each is a separate element, but they have a common rotor shaft. In either case, the speed of rotation of the servomotor provides the mechanical input to the rate generator.

In special cases, where a variation in the ratio of output voltage to revolutions per minute is critical, a temperature compensated rate generator is used. The output voltage of a temperature compensated rate generator is not affected by temperature.

ELECTRICAL AND ELECTRONIC COMPUTING ELEMENTS OF ANALOG COMPUTERS

PARALLEL RESISTOR NETWORKS

Electromechanical computing elements convert mechanical computer variables into voltages, which in many instances are algebraically added together. The basic electrical computing element that does this job is the parallel resistor network. Its circuit arrangement is shown in figure 6-28.

The parallel resistor networks, called network boxes, have an output that is the algebraic sum of two or more inputs. The network box contains precision resistors and capacitors. The precision resistors are noninductive, wire wound, and hermetically sealed in a metal can. The resistance of the resistors is normally kept within the 0.02- to 3.0-megohm (MΩ) range. The maximum is the point above which there would be too great a susceptibility to pickup through inductive coupling between elements. A capacitor is connected across each resistor to compensate for any inductance created by the winding of the resistor. The capacitors are preset, and should never be changed. In later illustrations the capacitors are not shown since they neutralize only the inductance of a resistor.

The resistance can and capacitors are enclosed in a metal box, which is also sealed. The input and output leads are connected to pins mounted on a plug; therefore, the network box is a plug-in module. The output of the network box is always through a coaxial cable. This prevents stray pickup (noise). The input connections are unshielded pins.

The principle advantage of using parallel resistors for the addition of voltages is simplicity; input signals may all be referred to a common grounded return. Without this feature all of the input sources would have to be electrically isolated from each other.

A network box can electrically produce the algebraic sum of two or more voltages, which are either in phase or 180° out of phase. Consider the circuit in figure 6-29 where two equal voltages of the same polarity are to be combined. Voltages E_1 and E_2 are connected in series with resistors R_1 and R_2, respectively, and terminate at a common junction or node point.

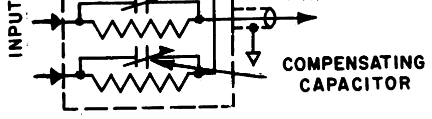

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Figure 6-28.—Parallel resistor network.

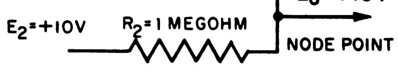

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Figure 6-29.—Parallel resistor summation network.

The voltage at the node point is not the actual sum of the voltages but is proportional to that sum. In this problem, the sum of the two voltages should be +20 volts; however, only 10 volts appear at the output. If one of the inputs is changed to 20 volts, the output should be 30 volts. But, only 15 volts will appear at the output. For these two examples, only one-half of the sum of the two voltages appears at the output. If a third input resistor were added to the circuit and all three of the input voltages were +10 volts, the output voltage would be +10 volts, or only one-third of the total input voltage. In each case there was a scale change, one-half of the total input for the first two problems and one-third of the total input for the last example. Therefore, the circuit is not always accurate for algebraic addition of analog voltages. Among its drawbacks are:

1. Loading at the output changes the effective value of the output impedance and produces a direct scaling error.
2. A scaling error is introduced if the number of input sources is changed.
3. Each of the input impedances, R_1, R_2, and R_3, acts as a load on all of the inputs simultaneously. This causes interaction among the input voltages.
4. For accuracy, the impedances R_1, R_2, and R_3 should be high compared to the respective input impedances. This often raises the overall impedance level of the circuit to a point where pickup from extraneous voltages may become a problem.
5. To minimize the effects of interaction among the various inputs, the output voltage should be as close to ground potential as possible. This results in a high attenuation of signal from input to output.
6. The accuracy of the parallel addition circuit depends directly upon the stability of the impedances, R_1, R_2, R_3, etc. Hence components must be precise.

All of the above point to the same thing–a feedback amplifier is needed in the circuit to prevent loading and to provide summation of voltages without a scale change unless desired.

Feedback Amplifier

The feedback amplifier (fig. 6-30) used with the network box is also a plug-in module, and may use either tubes or transistors. Its components are interconnected by either wiring or printed circuits. Generally, each feedback amplifier has three stages of amplification; however, in some special cases it may have five.

When a feedback amplifier is in a computing loop, an additional resistor, R_f, designated the feedback leg, is required for the negative feedback. The negative (180° out of phase) output of the amplifier is impressed across the feedback resistor because the amplifier and resistor are in parallel.

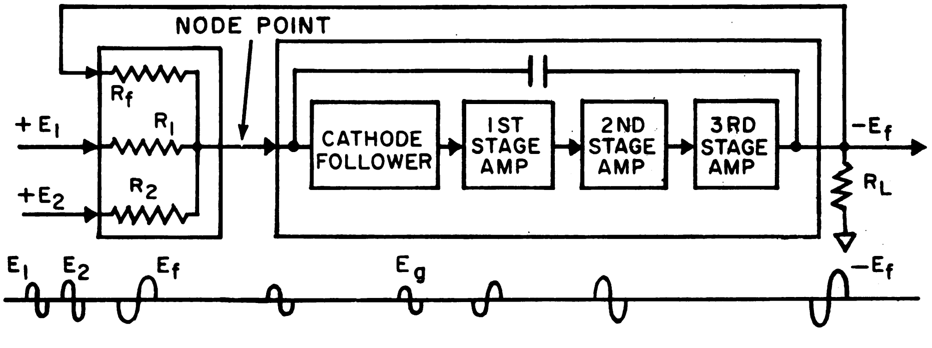

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Figure 6-30.—Parallel addition circuit using a feedback amplifier.

Therefore, the output of the network box, or node point, is automatically maintained close to ground potential. The feedback amplifier actually multiplies the small a.c. output (Eg) by the amplifier gain factor (u). The amplifier solves the equation $-Ef = Eg$. The forward gain of the amplifier is high (up to 20,000:1) to ensure accuracy. Negative feedback within the amplifier keeps the gain constant regardless of aging components, and it minimizes harmonic distortion in the amplifier. The amplifier has exactly a 180° phase shift from input to output. A capacitor, connected between the input and output, compensates for undesired phase shift.

The feedback amplifier features high input impedance and low output impedance. Its output is fed into a resistive load. If the load does not offer the correct resistance, a fixed resistor is connected across the amplifier output to provide the correct load.

Even though the amplifier does amplify its input to produce the feedback voltage, the overall loop amplification is determined by the resistance ratio of the feedback resistor and the input resistors. This will be clarified later.

Although the feedback amplifier does not actually perform any computation other than the multiplication of its input voltage times the amplifier gain, it is always used with network boxes in computing loops which perform the functions listed below. The amplifier has various names: isolation amplifier, feedback amplifier, operational amplifier, computing amplifier, and summation amplifier. The various computing loops, in which feedback amplifiers are used, perform any or all of the following.

1. They reverse the sign of a voltage, with or without a change in overall loop amplification. Often, it is necessary to change the polarity of a voltage so that a plus or minus voltage is available for the solution, of the problem. Also, at times it is necessary to change the overall loop amplification, which in turn changes the scale factor of the output with respect to the input.
2. They isolate and/or eliminate loading of one computing element from another. In electrical analog computers it is necessary to supply extremely accurate voltages from computing elements (potentiometers, sine and cosine potentiometers, and resolvers) to the same or other types of computing elements. If these elements are connected directly, accuracy is lost due to loading.
3. They provide a voltage proportional to the algebraic sum of two or more input voltages. Although a summing loop can be considered as a summation of analog voltages, the real job of the loop is to determine the algebraic sum of computer variables. These variables are represented by the analog voltages; hence, scale factors are assigned to each. The computer variables that the voltages represent must have a common reference axis; therefore, the input voltages must be in phase or 180° out of phase. Otherwise, an error will result.

Sign Reversing Loop with Unity Gain

The most basic loop employing a network box and feedback amplifier is the sign reversing loop (inverter). The loop reverses the phase of the input voltage and maintains unity gain (1:1). The following is a description of how the loop works.

In figure 6-31, E_s and $-E_f$ are the effective input and output voltages; eg is the amplifier signal voltages; R_f is a fixed resistor located in the network box; and the R_L is a fixed load resistor at the output of the amplifier.

If +12 volts is applied to the input leg, current flows from ground through the input

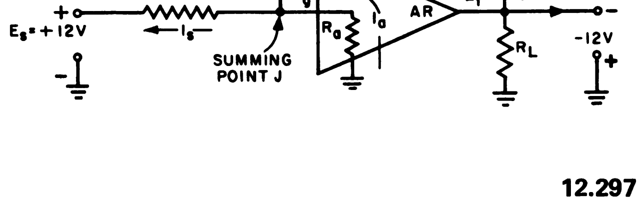

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Figure 6-31.—Sign reversing loop with unity gain (inverter).

impedance of the amplifier, through R_s to the signal source. This current is designated as I_a. It causes an input signal, eg, at summing point J, the input to the amplifier. The amplifier amplifies the input signal and provides degenerative (negative or inverse) feedback through R_f to summing point J. From point J, the feedback current flows through R_s to the signal source to ground and back to the amplifier. The feedback current is designated I_f. Thus, the current through R_s is

$$I_s = I_a = I_f$$

If the gain of the amplifier is designated as K, then, the output voltage, E_f, is K times as large as the input signal voltage. Thus, the output voltage is $E_f = -K(eg)$. In this equation, the minus sign before K indicates that there is a 180° phase displacement, or sign reversal, between eg and E_f. This is true because the amplifier has three stages of amplification. The gain of the amplifier is high; assume that it is 10,000 to one. Therefore, the input signal, eg, need be only 1,200 microvolts to attain a maximum value of -12 volts for E_f ($1/10{,}000 \times 12 = 0.0012$ volts).

According to Kirchhoff's law of electrical current, the algebraic sum of the currents entering a junction, such as summing point J, must be equal to the sum of the currents leaving the junction. Since the amplifier is designed to have practically infinite impedance at the input and between the input and output, the only currents at summing point J are I_f and I_s. This equation neglects the very small voltage drop across the input impedance of the amplifier, and will be discussed later. Therefore, the equation can be written

$$I_s + I_f = 0$$

Using this equation, the output voltage can be solved if the values of R_s, R_f, and E_s are known. Thus, the output voltage of the sign reversing loop is determined using the following formula.

$$I_s + I_f = 0$$

Rewrite as

$$I_s = -I_f$$

Substitute Ohm's law

$$\frac{E_s}{R_s} = \frac{-E_f}{R_f}$$

Multiply both sides by R_f

$$R_f\left(\frac{E_s}{R_s}\right) = -E_f$$

Substitute known values

$$1.0\left(\frac{12}{1.0}\right) = -E_f$$

Therefore,

$$E_f = -12 \text{ V}$$

The equation

$$E_s\left(\frac{R_f}{R_s}\right) = -E_f$$

expresses the relation between the input and output voltages of the sign reversing loop. The ratio of the output to input voltage is shown to equal the resistance ratio R_f/R_s.

If the E_s input is assigned a scale factor of 100 knots per volt, then an input of +12 volts would represent 1,200 knots. To satisfy a zero or null condition at summing point J, the feedback voltage must represent -1,200 knots. We can say, then, that there will be a null at summing point J when the inputs (+1,200 knots and -1,200 knots) are balanced. For a +12 volt input, the current through R_s and R_f is the same, $I = E/R = 0.000012$ ampere (amp or A). Therefore, this condition produces a zero, or null, at the input to the amplifier.

Features Provided by Negative Feedback

As explained in the *NEETS* module on amplifiers, negative feedback occurs when the amplifier output voltage is fed back to the input out of phase with the input voltage. Negative feedback is also degenerative or inverse feedback. Negative feedback produces several important effects. One effect is to make the gain, or output-input voltage ratio, of the loop much less than the gain of the amplifier. The voltage fed back from the amplifier output opposes the input voltage supplied through the input resistor, R_s, thereby reducing the effective signal voltage at the input of the amplifier.

As a result of negative feedback, the loop output-input voltage ratio is practically independent of the amplifier gain. If the amplifier gain should decrease, less voltage would be returned through the feedback path. Less voltage would be available to oppose the input voltage at the amplifier input. Consequently, the signal voltage, eg, would be greater; in fact, sufficiently greater to compensate very nearly for the loss of gain.

Another feature gained by negative feedback is an output voltage which is practically independent of output load. An increase in the load might tend to reduce the output voltage, but if the output voltage were reduced, less feedback would take place. Less feedback would increase the signal voltage, eg, and would thereby compensate for the reduction in output voltage. With negative feedback, the effective resistance between the output terminals of the amplifier is less than an ohm. Any load having a resistance measured in thousands of ohms, therefore, has small effect.

Scale Changing (Multiplication and Division)

It is often necessary for the output of a loop to have a different unit per volt ratio than the input. This is referred to as a scale changing.

Consider the loop illustrated in figure 6-32. The loop's input voltage is +5 volts and each volt represents 100 knots; therefore, the input represents 500 knots. Using the formula previously determined

$$-E_f = E_s\ (R_f/R_s)$$

the magnitude of the feedback, or output, voltage can be determined. Thus,

$$-E_f = E_s\ (R_f/R_s)$$

$$-E_f = 5(1.0/2.0)$$

$$E_f = -2.5\text{ V}$$

To determine the scale factor of the output voltage, multiply the input scale factor by the resistance ratio of the input leg over the feedback leg (2.0/1.0). Thus,

$$\text{output scale factor} = \text{input scale factor}\ (R_s/R_f)$$

$$\text{output scale factor} = 100(2.0/1.0)\text{, or }200\text{ kn/V}$$

Therefore, to satisfy a zero, or null, at the input to the amplifier only -2.5 volts with a scale factor of 200 knots per volt (-500 knots) is required to balance the input voltage, 5 volts at 100 knots per volt (500 knots).

The zero condition at the input to the amplifier can be seen more clearly if the current through resistors R_s and R_f is considered. If an input of 5 volts is dropped across resistor R_s, then the current through the resistor is

$$I_s = \frac{E}{R}$$

$$I_s = \frac{5}{2{,}000{,}000}$$

$$I_s = 0.0000025\text{ A}$$

The current through R_s also flows through the feedback resistor, R_f. However, the

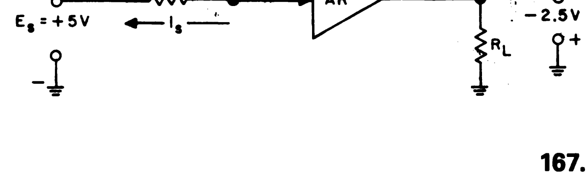

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Figure 6-32.—Basic circuit for scale changing.

resistance of this resistor is only 1 megohm. Thus, the voltage across R_f is

$$-E_f = I_f \times R_f$$

$$-E_f = 0.0000025 \times 1{,}000{,}000$$

$$E_f = -2.5\text{ V}$$

Because of the resistance ratio of the feedback leg to the input leg (R_f/R_s), the output of the amplifier will be only -2.5 volts, to provide a null at the input of the amplifier. Thus, the scale factor of the input voltage has been changed from 5 volts at 100 knots per volt to 2.5 volts at 200 knots per volt.

The basic scale changing circuit provides an output of less than unity gain; yet, the output information represents the input information. But, ratios as common as 1:2 for the feedback to input leg are not often encountered in analog computer circuits. Usually, the ratio for the feedback to input leg has some odd ratio, not easily recognized. For instance, consider a circuit that might be used to convert knots into yards per second (yd/s). Knots can be converted to yards per second by multiplying knots by a constant 0.563.

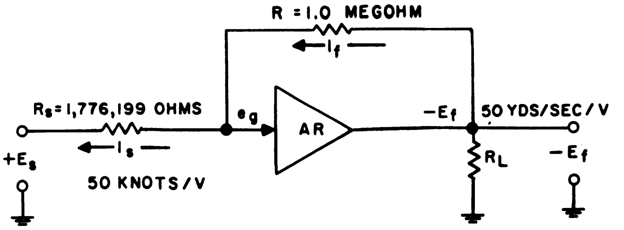
We arrive at this constant in the following manner.

> If a ship traveled one nautical mile (2027) yards in one hour (3600 seconds), how far would the ship travel in one second?

$$\begin{array}{r l} & 0.563\text{ yd/s} \\ 3600\text{ s} & \overline{)\,2027\text{ yd}} \end{array}$$

Therefore, 1 knot is equal to 0.563 yards per second. If a ship traveled 2 nautical miles in 1 hour, it would naturally travel at twice the yards per second, or 1.126 yards per second.

$$\text{yd/s} = \text{kn} \times 0.563$$



167.74

Figure 6-33.—A basic circuit for converting knots into yards per second.

The ratio of R_f/R_s in the network box provides the constant, 0.563, for the loop illustrated in figure 6-33. Whenever possible, the resistance of the feedback leg is kept at a value of 1 megohm, therefore, the input leg must have more resistance to provide the correct ratio. Thus, the ratio of R_f/R_s is

$$\frac{R_f}{R_s} = \frac{1{,}000{,}000}{1{,}776{,}199}, \text{ or } 0.563$$

The scale factors assigned to the input and output of the loop may seem confusing because the input scale factor is 50 knots per volt while the output scale factor is 50 yards per second per volt. However, scale factors are usually expressed in units per volt; therefore, in order for the output to represent the input, the output scale factor already includes the constant, 0.563. This has been done mathematically during the design of the loop.

A comparison of the output and input will show how the output scale factor is expressed as 50 yards per second per volt. When 50 yards per second appears at the output of the loop, -1 volt is dropped across the feedback resistor, R_f. The current through R_f is

$$I_f = E = \frac{1}{1{,}000{,}000}$$

Therefore,

$$I_f = 0.000001\text{ A}$$

To provide a null at the amplifier input, the input voltage will represent some value of knots that is equivalent to 50 yards per second. Mathematically, 50 yards per second can be converted into knots by dividing by the constant, 0.563. This division would produce

88.81 knots. Electrically, the constant is provided by the ratio of the network box. Since the input scale factor is expressed in knots per volt, and due to the ratio of R_f/R_s, the voltage felt across the input resistor, R_s, will be larger than the feedback voltage. Thus,

$$E_s = I_s \times R_s$$

$$E_s = 0.000001 \times 1{,}776{,}199$$

$$E_s = 1.776{,}199\ \text{V}$$

Therefore, to provide a -1 volt output from the loop, the input voltage must be 1.776 volts. Since the scale factor of the input voltage is 50 knots per volt, this voltage represents 88.81 knots (1.776 × 50 knots per volt = 88.81).

Some input and output voltages and what each represents are tabulated in table 6-3.

Remember that the ratio of R_f/R_s controls the overall gain of the loop. The resistance value of the input resistor, for the loops discussed, was equal to, or larger than, the feedback resistor. Therefore, the loop gain was equal to, or less than, unity. If the resistance of the input resistor is less than that of the feedback resistor, the overall gain of the loop will be increased. For instance, consider the circuit in figure 6-34 which might be used to convert yards into feet.

Since there are 3 feet in each yard, the ratio of R_f/R_s is selected as 3:1. The scale factor of the output voltage already includes the constant,

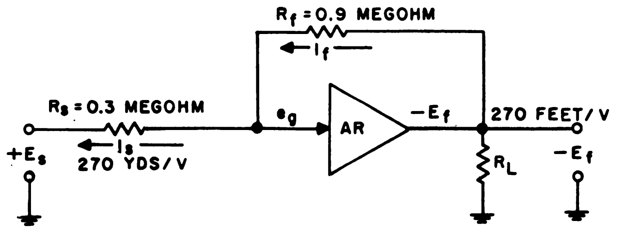


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Figure 6-34.—A basic circuit for converting yards into feet.

Table 6-3.—Input/output voltage converted from knots to yards per second

Input Voltage	Represents Knots	Output Voltage	Represents Yards/second
1V	50	0.563V	28.15
2V	100	1.126V	56.30
3V	150	1.689V	84.45
4V	200	2.252V	112.60
5V	250	2.815V	140.75
6V	300	3.378V	168.90
7V	350	3.941V	197.05
8V	400	4.504V	225.20
9V	450	5.067V	253.35
10V	500	5.630V	281.50

167.748

in this case, 3. If 1 volt is the input to the loop the output will be

$$-E_f = E_s\ (R_f/R_s)$$

$$-E_f = 1(.9/.3)$$

$$E_f = -3\ V$$

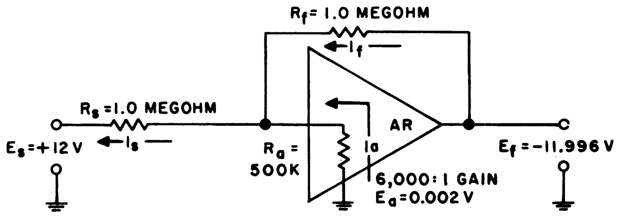
Therefore, this loop has an overall gain of 3:1; that is a 1 volt input will produce -3 volts at the output. If 1 volt at the output represents 270 feet, then

$$3\ V\ \chi\ 270\ ft = 810\ ft\ or\ 270\ yd$$

Again, a comparison of output to input will show how the output scale factor is expressed in feet per volt, while the input scale factor is in yards per volt. The ratio of R_f/R_s is such that only .333 volt is required at the input of the loop to produce a -1 volt output. Several input and output voltages and what each represents are tabulated in table 6-4.

GAIN COMPENSATING RESISTOR

During the discussion of the various loops, the slight voltage drop across the input impedance of the amplifier, as mentioned earlier, has been neglected. A close look at the overall circuit shows that the output is not quite equal to the input if this is neglected. The loop diagrammed in figure 6-35 uses a low gain amplifier to illustrate the loss.



$I_s = I_a + I_f$

I_s = E/R ; 12/1,000,000 = 0.000012 amp OR 12 μa.

I_a = E/R ; .002/500,000 = 0.000000004 amp OR 4000 μμa.

$I_f = I_s - I_a$; I_f = 12 μa − 4,000 μμa = 11.996 μa.

$E_f = I_f$ X R_f ; E_f = 1.0 MEGOHM X 11.996 μa = 11.996 VOLTS. THUS, THE OUTPUT IS 0.004 VOLTS LESS THAN THE INPUT.

167.76

Figure 6-35.—Loss of output voltage due to input impedance of amplifier.

To correct this slight loss, a gain compensating resistor, R_g, is placed in series with the feedback resistor (fig. 6-36). The value of the resistor is chosen so that with a +12 volt input, the output is exactly -12 volts.

In addition to compensating for the slight drop across the amplifier, the gain compensating resistor also reduces the feedback current by the exact amount of I_a. So, the original assumption, where I_a was assumed to be zero, is now compensated for because

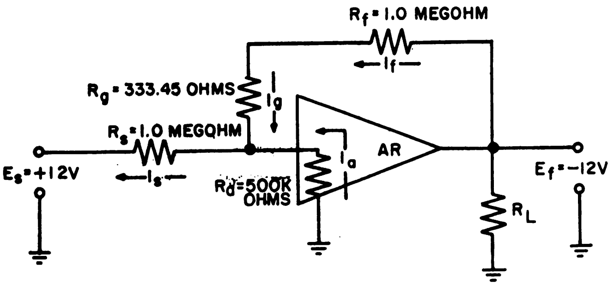
$$I_s = (I_f - I_a) + I_a$$

Therefore, $I_s = I_f$ is a true statement.

Table 6-4.—Input/output voltage converted from yards to feet

Input Voltage	Represents	Output Voltage	Represents
0.333V	90 yards or 270 feet	1V	270 feet or 90 yards
0.667V	180 yards or 540 feet	2V	540 feet or 180 yards
1.000V	270 yards or 810 feet	3V	810 feet or 270 yards
1.333V	360 yards or 1,080 feet	4V	1,080 feet or 360 yards

167.749



167.77

Figure 6-36.—Gain compensating resistor used to increase output voltage.

The size of the gain compensating resistor can be computed using the current through the feedback leg and the voltage dropped across R_f. The voltage drop across R_g is determined in the following manner (using values determined in figure 6-35).

$$E_g = E_s - E_f$$

Thus,

$$E_g = 12 - 11.996, \text{ or } 0.004 \text{ V}$$

The current through R_g is the same as that through R_f, thus,

$$I_g = I_s - I_a$$

$$I_g = 12\ \mu\text{A} - 4000 \text{ pA, or } 11.996\ \mu\text{A}$$

(μA - microampere; pA - picoampere)

Substituting these values into the formula,

$$R_g = \frac{E_g}{I_g}$$

the value of the gain compensating resistor is determined. Thus,

$$R_g = \frac{0.004}{0.000011996}, \text{ or } 333.45\ \Omega$$

The feedback resistor and gain compensating resistor are in series; therefore, the total resistance of the feedback leg is

$$R_{tf} = R_f + R_g$$

$$R_{tf} = 1{,}000{,}000 + 333.45 = 1{,}000{,}333.45\ \Omega$$

With more resistance in the feedback leg than in the input leg, the amplifier will produce -12 volts, thus compensating for the loss of voltage due to the input impedance of the amplifier. Thus, the voltage out is

$$E_{out} = I_f \times R_{tf}$$

$$E_{out} = .000011996 \times 1{,}000{,}333.45, \text{ or } -12 \text{ V}$$

Normally, the schematic of a network box does not show the gain compensating resistor, which does nothing but compensate for the loading effect of the amplifier.

From the discussion you can see that a particular network box is designed for an amplifier having a specific gain. The feedback amplifier has been standardized to a great extent and is interchangeable with another having the same drawing number.

SUMMATION OPERATIONS IN ANALOG COMPUTERS

Summation operations (addition and subtraction) are fundamentally important. Take the solution of the fire control problem. Here, it is necessary to perform summation many times. In modern analog computers, the computer variables are converted into electrical signals, then combined in a loop called a summing computing loop. A typical summing computing loop includes either a feedback amplifier or a servomechanism, depending on whether an electrical or mechanical output is desired. If an electrical output is needed, an amplifier is used. If the output is mechanical, then a servomechanism is used. In either case, the summation operation is performed by a network box.

BASIC SUMMING COMPUTING LOOP

The loop discussed earlier, which used network boxes, did not add voltages. For a loop to perform summation, two or more input voltages are required. Such a loop is illustrated in figure 6-37. The loop determines the algebraic sum of three input voltages. To perform summation, a four-legged network box is used, three legs for the input voltage and the fourth leg for the feedback voltage. The feedback leg is sometimes referred to as the Great Equalizer because it carries the current that balances or nulls out the currents in the other legs.

The three voltages to be added have the same scale factor (1,000 yards per volt). The resistance ratios (R_f/R_1, R_f/R_2, R_f/R_3) are chosen to provide summation of the voltages without a scale change. Therefore, the output voltage should be 11 volts, with a scale factor of 1,000 yards per volt, or a total of 11,000 yards.

$$I_f = I_1 + I_2 + I_3$$

Substituting Ohm's law

$$E_f/R_f = E_1/R_1 + E_2/R_2 + E_3/R_3$$

Multiply both sides by R_f

$$E_f = E_1(R_f/R_1) - E_2(R_f/R_2) - E_3(R_f/R_3)$$

Substitute know values

$$-E_f = 5(1/1) + 2(1/1) + 4(1/1)$$

$$-E_f = 5 + 2 + 4$$

$$E_f = -11 \text{ V}$$

As the ratio of the feedback leg to each of the inputs is 1:1, then the scale factor of the output voltage is the same as the inputs, or 1,000 yards per volt. Therefore, 11 volts at 1,000 yards per volt represents a total of 11,000 yards. Thus, the summing computing loop uses a multiple input network box to produce an output which is the sum of its three inputs. The sign of the output voltage is negative because there are an odd number of stages in the amplifier. However, if a negative voltage cannot be used at this stage of computation, a sign reversing loop could be used to reverse the polarity of the voltage.

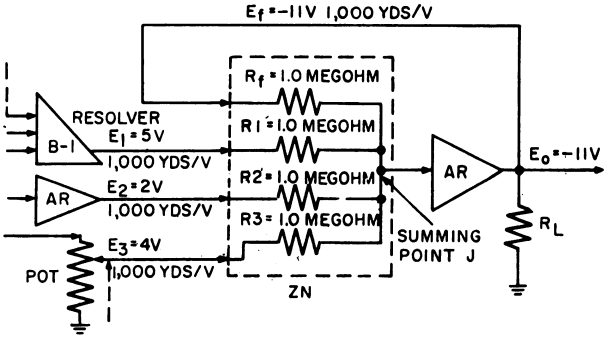


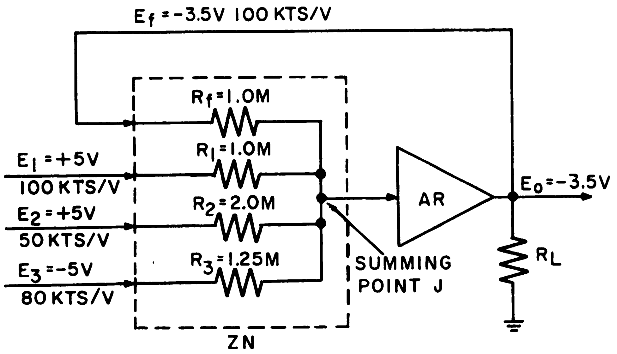
Figure 6-37.—Basic summing computing loop.

Although addition has been explained as a summation of voltages, the real job of the summing computing loop is to add physical units, such as yards and knots. Therefore, knowledge in equals knowledge out. Thus, each computing loop will have scale factors assigned.

SUMMATION OF VOLTAGES WITH DISSIMILAR SCALE FACTORS

In an analog computer, it is often necessary to add quantities that have different values of units per volt (scale factors). To add these correctly, all the inputs must be converted to a common scale, that is, the same units to volt ratio. The design engineer selects the suitable ratios for the network box so that each input is converted to a common scale. However, the ratios selected must be such that the output cannot exceed the maximum rated output of the feedback amplifier or the computer reference voltage applied to a potentiometer.

As illustrated in figure 6-38, three voltages, two positive and one negative, each with a different value of knots per volt, are to be added algebraically by the summing computing loop. The negative input voltage will not present a



167.79

Figure 6-38.—Summation of voltages with dissimilar scale factors.

problem, as the current through R_3 will cause a positive potential at summing point J, which in effect will reduce the current through the feedback leg. According to Kirchhoff's law of electrical current, the algebraic sum of the current entering a junction must be equal to the sum of the current leaving the junction. Therefore, the following equation can be written.

$$I_f + I_3 = I_1 + I_2$$

The equation of the above can be rewritten as

$$I_f = I_1 + I_2 - I_3$$

and used to compute the output voltage.

$$E_f/R_f = E_1/R_1 + E_2/R_2 - E_3/R_3$$

$$E_f = E_1(R_f/R_1) + E_2(R_f/R_2) - E_3(R_f/R_3)$$

$$-E_f = 5(1/1) + 5(1/2) - 5(1/1.25)$$

$$-E_f = 5 + 2.5 - 4$$

$$E_f = -3.5 \text{ V}$$

As R_f and R_1 have a 1:1 ratio, this sets the common scale factor for the output voltage. Thus,

$$\text{common output scale factor} = E_1 \text{ scale factor } (R_1/R_f)$$

$$\text{output scale factor} = 100 \text{ kn/V } (1/1), \text{ or } 100 \text{ kn/V}$$

The resistance value of the other two input legs is selected so as to convert the knots to volt ratio to the common scale of 100 knots per volt. Thus, the output scale factors for the other two legs are

$$\text{output scale factor} = E_2 \text{ scale factor } (R_2/R_f)$$

$$\text{output scale factor} = 50 \text{ kn/V } (2/1), \text{ or } 100 \text{ kn/V}$$

$$\text{output scale factor} = E_3 \text{ scale factor } (R_3/R_f)$$

$$\text{output scale factor} = 80 \text{ kn/V } (1.25/1), \text{ or } 100 \text{ kn/V}$$

Therefore, the output factor is common for each of the three input voltages. Thus, the summing computing loop has algebraically added the three voltages with different scale factors to produce an output of 3.5 volts, which represents 350 knots.

The summing computing loop just described is not suited for practical use, but is sufficient for explaining the summation of positive and negative input voltages and the principles of scale changing. Let's examine the reason it is not practical.

When a network box is designed for use in a summing computing loop, the design engineer must take into consideration the maximum level of the input voltages as well as the maximum output voltage. The ratio of the feedback leg to each input leg must be such that the amplifier will not saturate. The magnitude of the output voltage, along with the scale factor assigned, must be suitable for the next step of computation.

Different computers use different computer reference voltages. A typical example is 12 volts. Others are 16 volts, 20 volts, 24 volts, 30 volts, and 40 volts. If a computer uses a 12-volt reference, all the resolvers, potentiometers, and feedback amplifiers are designed to handle this level of voltage. If it were exceeded in the problem computation, the amplifier would saturate and cause an error in computation.

Illustrated in figure 6-39 is the same summing computing loop previously described, except that the input voltages have been changed. (The scale factors are the same.)

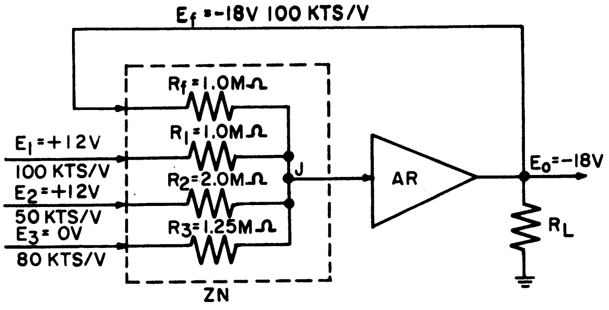


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Figure 6-39.—Impractical summing computing loop.

Summation of the input voltages should produce -18 volts, which is more than the amplifier can deliver. Thus, the amplifier is saturated, and an error exists.

Voltage Computation

$$E_f = E_1(R_f/R_1) + E_2(R_f/R_2) - E_3(R_f/R_3)$$

$$-E_f = 12(1/1) + 12(1/2) - 0$$

$$-E_f = 12 + 6$$

$$E_f = -18\ V$$

To prevent saturating the amplifier, different values of resistance for each of the input legs are incorporated in the network box. A summing computing loop that can perform summation is shown in figure 6-40.

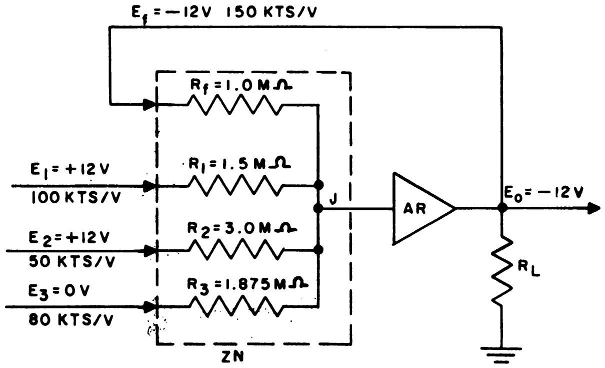

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Figure 6-40.—A practical summing computing loop.

Voltage Computation

$$E_f = E_1(R_f/R_1) + E_2(R_f/R_2) - E_3(R_f/R_3)$$

$$-E_f = 12(1/1.5) + 12(1/3) - 0$$

$$-E_f = 8 + 4 - 0$$

$$E_f = -12\ V$$

A maximum input of +12 volts is applied to two of the input legs as E_1 and E_2. Zero volts is applied as input voltage E_3. Under these conditions, the loop should produce a maximum output that is within the limits of the amplifier. Thus, with maximum input the output is computed in the following manner.

Output Scale Factor Computation

100 kn/V(1.5/1) = 150 kn/V

50 kn/V(3/1) = 150 kn/V

80 kn/V(1.875/1) = 150 kn/V

Special Divider Networks

In network boxes, it is common practice to use a feedback resistance of 1 megohm (MΩ).

With this value of R_f, the value of each input leg is calculated to obtain the correct ratio between the feedback leg and input leg so that all inputs are converted to a common scale. However, in computing the ratios it may be found that the resistance of one or more of the input legs may exceed 3 megohms. Since a 3-megohm resistor is susceptible to pickup through inductive coupling with other resistors in the network box, a special divider network is substituted for the large resistor to reduce its size but keep the computation the same.

Illustrated in figure 6-41 is a circuit where the ratio desired is such that to use a single resistor would require one which exceeds the maximum limit of 3 megohms.

The circuit provides a scale change of 1:12 using a single resistor in the input leg. The scale factor of the input voltage is 1,000 yards per volt. Due to the ratio between R_f and R_1, the output voltage is -1 volt with a scale factor of 12,000 yards per volt.

$E_f = E_1(R_f/R_1)$ output scale factor = input scale factor (R_1/R_f)

$-E_f = 12(1/12)$ output scale factor = 1,000 yd/V (12/1)

$E_f = -1$ V output scale factor = 12,000 yd/V

If such a situation arises during the design of a computer, a single divider network would be substituted for the large input resistor. Illustrated in figure 6-42 is a circuit using a special divider. It will accomplish the same change with no resistor exceeding the maximum limit of 3 megohms. This circuit, which uses no resistor above 1 megohm, effectively offers the same resistance as the one using 12 megohms.

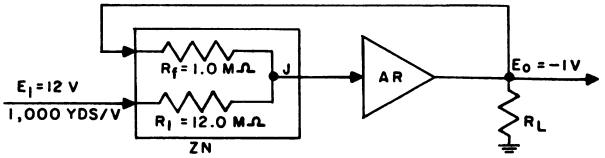

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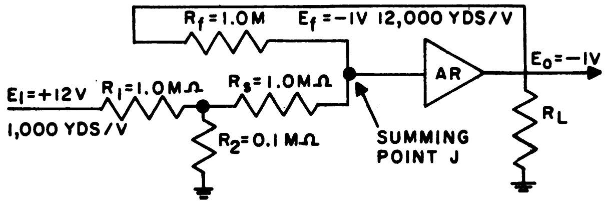
Figure 6-41.—Improper selection of resistor values.



167.83
Figure 6-42.—Circuit using a special divider network.

As stated previously during the explanation of network boxes, summing point J is at virtual ground. Therefore, the input circuit may be redrawn (fig. 6-43) as a series-parallel circuit. The total resistance of this series-parallel circuit is found using the following formula.

$$R_t = R_1 + \frac{R_s \chi R_2}{R_s + R_2}$$

$$R_t = 1.0 + \frac{(1.0)\quad(.1)}{1.0 + .1}$$

$$R_t = 1.0 + .090909$$

$$R_t = 1.090909\ \text{M}\Omega$$

Knowing the value of R_t and the applied voltage, the total current in the special divider network can be determined.

$$I_t = \frac{E_{in}}{R_t}$$

$$I_t = \frac{12}{1{,}090{,}909\ \Omega}$$

$$I_t = 11\ \mu\text{A}$$

By knowing the total current through the special divider network, it is possible to find the

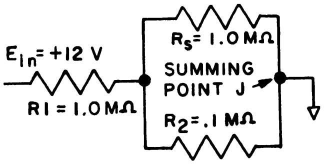


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Figure 6-43.—Input circuit redrawn as a series-parallel circuit.

voltage drop across each portion of the circuit. The voltage drop across R_1 is

$$E_1 = I_t \times R_1$$

$$E_1 = 11\ \mu A \times 1.0\ M\Omega$$

$$E_1 = 11\ V$$

If 11 volts is dropped across R_1, then 1 volt must be felt across R_s and R_2. Thus, the current through each leg of the parallel circuit is

$$I_2 = \frac{E_2}{R_2} \qquad I_s = \frac{E_s}{R_s}$$

$$I_2 = \frac{1\ V}{0.1\ M\Omega} \qquad I_s = \frac{1\ V}{1.0\ M\Omega}$$

$$I_2 = 10\ \mu A \qquad I_s = 1\ \mu A$$

If only 1 microamp of current is flowing through R_s, the same current is passing through the feedback resistor R_f. Therefore, $I_f = I_s$. Due to the special divider network in the input leg, an input voltage of +12 volts will cause an effective input voltage of +1 volt (which is across R_s) to be felt at summing point J. Therefore, the amplifier need produce only a -1 volt output to provide a zero or null condition at summing point J. Thus,

$$I_f = I_s$$

$$\frac{E_f}{R_f} = \frac{E_s}{R_s}$$

$$E_f = R_f\ (E_s/R_s)$$

$$-E_f = 1\ (1/1)$$

$$E_f = -1\ V$$

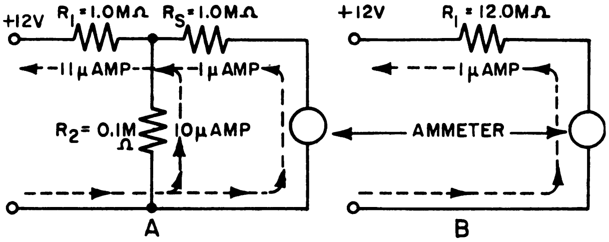

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Figure 6-44.—Similar resistor networks.

The special divider network (fig. 6-44A), which uses no resistor above 1 megohm, will present an effective resistance of 12 megohms as the input leg. This is the same as a 12-megohm resistor would. (See fig. 6-44B.) Thus, the current through R_s is the same as if the input leg consists of a 12-megohm resistor (1 microamp in either circuit). The special divider network does this because it is a voltage divider and most of the current is passed through R_2 (10 microamps) while only a very small portion (1 microamp) of the current is flowing through resistor R_s.

A very useful formula to find the effective resistance of a special divider network is

$$\text{effective resistance} = R_1 + R_s + \left(\frac{R_1 \times R_s}{R_2}\right)$$

$$\text{effective resistance} = 1.0 + 1.0 + \left(\frac{1.0 \times 1.0}{0.1}\right)$$

$$\text{effective resistance} = 1.0 + 1.0 + 10.0$$

$$\text{effective resistance} = 12.0\ M\Omega$$

When more than one special divider network is required in a summing computing loop, it is advantageous, if at all possible, to use a multiple divider network rather than two special divider networks. The summing computing loop illustrated in figure 6-45 requires two special divider networks because the resistance of two of the input legs is above 3 megohms.

Rather than use two special divider networks, one multiple divider network is used, as drawn in figure 6-46. In this network, resistor

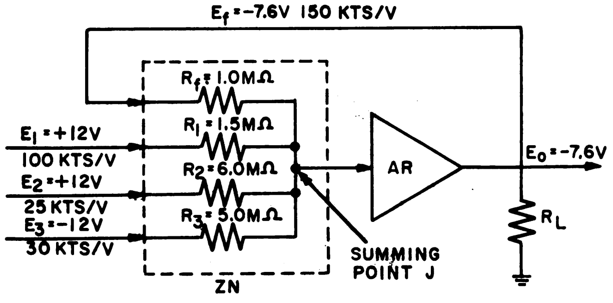

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Figure 6-45.—Circuit requiring two special divider networks.

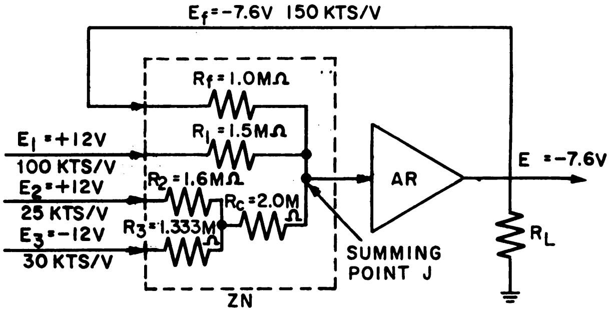

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Figure 6-46.—Circuit using a multiple divider network.

R_c is common to both the E_2 and E_3 input legs. The value of each resistor used in the input leg of E_2 and E_3 is selected so that the input cirrcuit will deliver the same current to summing point J as the original circuit when the multiple divider network is supplied with the same input voltage.

The effective resistance formula is used to determine the effective resistance of input legs E_2 and E_3 so that the total current through R_c can be computed. Thus,

Effective resistance of E_2 leg

$$R_{eff} = R_2 + R_c + \frac{R_2 \times R_c}{R_3}$$

$$R_{eff} = 1.6 + 2.0 + \frac{1.6 \times 2.0}{1.333}$$

$$R_{eff} = 6\ \text{M}\Omega$$

Effective resistance of E_3 leg

$$R_{eff} = R_3 + R_c + \frac{R_3 \times R_c}{R_2}$$

$$R_{eff} = 1.333 + 2.0 + \frac{1.333 \times 2.0}{1.6}$$

$$R_{eff} = 5\ \text{M}\Omega$$

The current actually flowing through resistor R_c is the difference between the currents resulting from the +12 volt and -12 volt inputs, or a total of .4 microamps.

Current caused by +12 V

$I_c = E/R$

$12/6.0\ \text{M}\Omega = 2\ \mu\text{A}$

Current caused by -12 V

$I_c = E/R$

$12/5.0\ \text{M}\Omega = 2.4\ \mu\text{A}$

These two currents subtract from each other; therefore, a total of .4 microamps will flow through resistor R_c to combine with the 7.6 microamps through resistor R_f to provide the 8 microamps required for resistor R_1.

The three inputs represents a total of 1,140 knots. Therefore, if the summing computing loop is functioning properly, the output voltage will represent 1,140 knots. Thus,

Input in knots

12 V x 100 kn/V = 1,200 kn

12 V x 25 kn/V = 300 kn

-12 V x 30 kn/V = -360 kn

1,140 kn

Output in knots

-8.0 V x 150 kn/V = 1,200 kn

-2.0 V x 150 kn/V = 300 kn

+2.4 V x 150 kn/V = -360 kn

-7.6 V x 150 kn/V = 1,140 kn

MULTIPLICATION AND DIVISION OPERATIONS IN ANALOG COMPUTERS

Multiplication and division operations in an analog computer are as important as summation operations. Multiplication may be performed electrically by amplifiers, and electromechanically by potentiometers. Multiplication and division in amplifiers were discussed previously and will not be covered here.

In an analog computer, the computer variables to be multiplied may be either voltages or motions (shaft rotations or positions). Therefore, multiplication of two variables may be performed by one of the following methods: volts χ motion, motion χ motion, and volts χ volts. Multiplication by each of these methods is discussed, and where the same elements can be used for division, this operation is also covered.

MULTIPLICATION OF TWO VARIABLES WITH A POTENTIOMETER

In the discussion of potentiometers, the potentiometer was used to convert a mechanical computer variable into a corresponding electrical value. This was referred to as mechanical to electrical conversion. Actually, the potentiometer multiplied a mechanical shaft position by a constant voltage; or, in other words, a variable was multiplied by a constant.

The potentiometer shown in figure 6-47 multiplies two computer variables, one electrical and the other mechanical. This demonstrates volts χ motion multiplication. The potentiometer is applied with a voltage that can vary from -10 to +10 volts. This voltage represents a rate which is expressed in knots per volt. The mechanical input represents time in seconds, and can be varied from 0 seconds to 50 seconds at 5 seconds per turn of the 10-turn potentiometer. The output represents a distance and is expressed in yards per volt. Thus, the potentiometer will perform any multiplication problem, within limitations, involving rate χ time = distance.

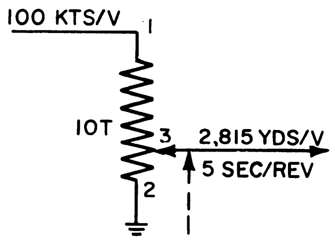

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Figure 6-47.—Potentiometer multiplication of two variables.

Previously, knots were converted to yards per second by the use of a constant, 0.563. The electrical scale factor, 2,815 yards per volt, includes the conversion of knots to yards per second. Therefore, the constant 0.563 is there but not seen. If a problem is computed mathematically however, the constant must be used.

The output scale factor can be determined by using the maximum input voltage and the two input scale factors. Thus,

Maximum input of knots is

$$100 \text{ kn/V } \chi \text{ } 10 \text{ V} = 1{,}000 \text{ kn}$$

Maximum yards per second is

$$1{,}000 \text{ kn } \chi \text{ } 0.563 = 563 \text{ yd/s}$$

Maximum yards per output is

$$563 \text{ yd/s } \chi \text{ } 50 \text{ s} = 28{,}150 \text{ yd}$$

Output in yards per volt is

$$28{,}150 \text{ yd}/10 \text{ V} = 2{,}815 \text{ yd/V}$$

If +6 volts were the input voltage and the slider were positioned to represent 20 seconds, the output voltage would be 2.4 volts. This voltage represents 6,756 yards. Mathematically, this can be proven using the following equation.

$$6 \text{ V at } 100 \text{ kn/V} = 600 \text{ kn}$$

$$600 \text{ kn } \chi \text{ } 0.563 = 337.8 \text{ yd/s}$$

$$337.8 \text{ yd/s } \chi \text{ } 20 \text{ s} = 6{,}756 \text{ yd}$$

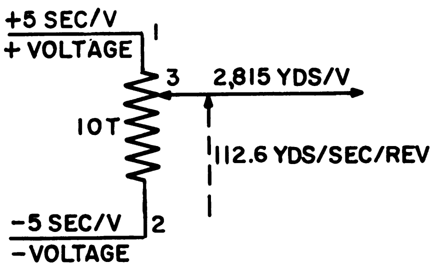
Previously, in the study of potentiometers, you saw that for one position of the slider a certain output voltage was obtained because the input voltage was constant. However, when the input voltage is variable, many different output voltages can be obtained for a given position of the slider. For example, several possible output voltages are listed below for the 20-second position of the slider, which is 0.4% of the total travel.

Input	Output
1,000 kn = +10 V	10 V χ .4 = 4 V or 11,260 yd
800 kn = +8 V	8 V χ .4 = 3.2 V or 9,008 yd
600 kn = +6 V	6 V χ .4 = 2.4 V or 6,756 yd
400 kn = +4 V	4 V χ .4 = 1.6 V or 4,504 yd
200 kn = +2 V	2 V χ .4 = 0.8 V or 2,252 yd
100 kn = +1 V	1 V χ .4 = 0.4 V or 1,126 yd
0 kn = 0 V	0 V χ .4 = 0.0 V or zero yd
-300 kn = -3 V	-3 V χ .4 = -1.2 V or 3,378 yd
-500 kn = -5 V	-5 V χ .4 = -2.0 V or 5,630 yd
-700 kn = -7 V	-7 V χ .4 = -2.8 V or 7,882 yd
-900 kn = -9 V	-9 V χ .4 = -3.6 V or 10,134 yd

DOUBLE-ENDED POTENTIOMETER AS A MULTIPLIER

Previously, a double-ended potentiometer was used to represent, electrically, a variable that could be either plus or minus with respect to a zero reference. Each end of the potentiometer was energized with a voltage—one end with a plus voltage, the other with a negative voltage. However, some analog computers also utilize a double-ended potentiometer to solve multiplication problems similar to the one just studied.

Shown in figure 6-48 is a double-ended potentiometer which can do the same multiplication problem just discussed. Each end of the potentiometer is energized by a voltage which represents time. Plus and minus voltages are used because the rate can be either plus or minus with respect to a zero reference. Therefore, a positive rate will produce a plus voltage and a negative rate will produce a minus voltage. The mechanical input represents the rate and is expressed in yards per second. The conversion from knots to yards per second has already been done. The zero position of the slider is at the center of the potentiometer, as is the case for all double-ended potentiometers. Thus, from the center of the potentiometer to either end represents 563 yards per second, or a total of 1,126 yards per second. A 10-turn potentiometer is used; therefore, the mechanical scale factor is 112.6 yards per second per revolution. The slider movement from the center to either end of the potentiometer will represent 1,000 knots.



TIME = 0 -50 SECONDS

RATE = -563 YDS/SEC TO +563 YDS/SEC,
OR TOTAL OF 1,126 YDS/SEC

167.89

Figure 6-48.—Double-ended potentiometer multiplication of two variables.

If the same multiplication problem, +600 knots χ 20 seconds = 6,756 yards, were presented to the potentiometers, the following conditions would exist:

1. ±4 volts would energize the potentiometer, thus representing 20 seconds (4 V χ 5 s/V = 20 s).

2. To represent +600 knots, the slider is rotated three revolutions so that the slider moves upward from the center a total of 337.8 yards per second (3 r χ 112.6 yd/s/r = 337.8 yd/s, or 600 kn).

3. The output voltage will be +2.4 volts (+4 V χ 2(3/10) = +2.4 V).

4. +2.4 volts, whose scale factor is 2,815 yards per volt, therefore represents 6,756 yards (2,815 yd/V χ 2.4 V = 6,756 yd).

CASCADING POTENTIOMETERS FOR MULTIPLICATION

So far in our discussion of linear potentiometers we have assumed that the output is connected to a high impedance which does not draw any appreciable amount of current from the potentiometer. The output is therefore directly proportional to the angle of rotation of the potentiometer shaft multiplied by the input voltage, or $E_o = E_{in} \chi \theta$. This equation may be rewritten as $E_o = E_{in}(R/R_t)$ if the potentiometer is labeled as shown in figure 6-49. Thus, when the input is 10 volts and the slider is positioned at its center of travel, the open-circuit voltage at the slider is 5 volts if measured with a vacuum-tube voltmeter. However, if an a.c. voltmeter with an impedance of 1,000 ohms per volt is used to measure the output voltage, the meter will draw current and the output voltage will be reduced to 4.444 volts. This type of a.c. voltmeter should not be used to measure the output voltage from a computing potentiometer.

The output voltage is determined by first computing the effective resistance of the circuit using the formula for effective resistance. Be careful, make certain you understand which resistance of the parallel branch is acting as an effective total resistance. It may be to your advantage to review the method of calculating effective resistance.

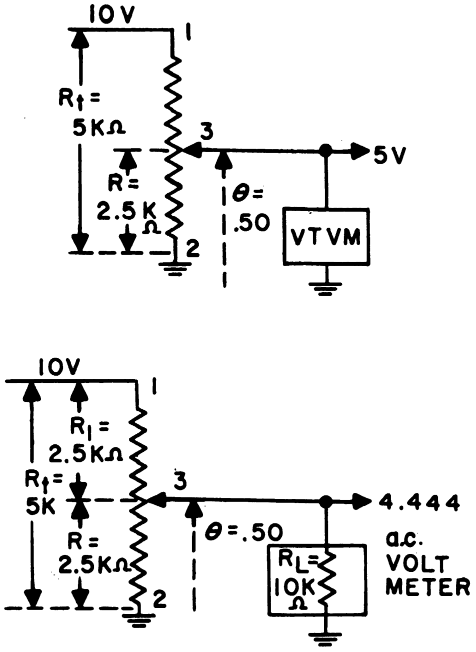


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Figure 6-49.—Loading effect of an a.c. voltmeter.

To obtain the electrical product of two mechanical variables, two potentiometers may be used. This is referred to as motion χ motion multiplication. However, if the potentiometers are connected as shown in figure 6-50A, the second potentiometer will draw current, thus loading the first potentiometer. As a result, the output voltage of the first potentiometer is not proportional to shaft rotation, but is less than that value by an amount which depends on the current drain as well as the position of the slider and its total resistance. Hence, the output of the second potentiometer is in error even though the output is connected to a high impedance load, because the potentiometers are connected so that a series-parallel circuit is formed, as shown in part B of the figure.

The formula for computing the total effective resistance of the circuit can be used.

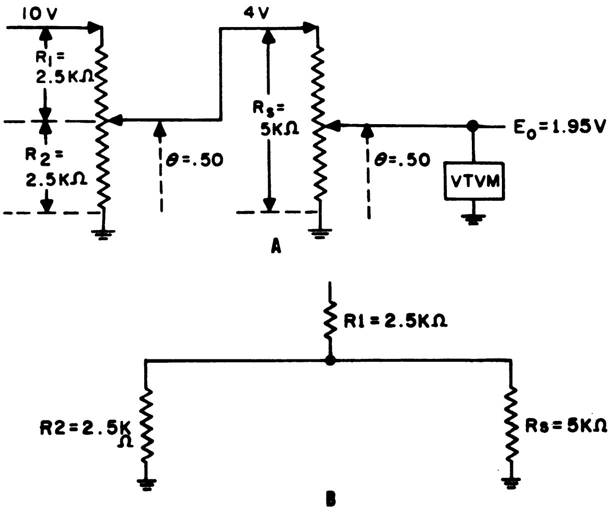

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Figure 6-50.—A. Loss of voltage due to loading a potentiometer; B. Series parallel circuit formed.

$$\text{Total } R_{eff} = R_1 + \text{Effective R of } R_s \text{ and } R_2$$

$$\text{Total } R_{eff} = R_1 + \frac{R_s + R_2}{R_s + R_2}$$

$$= 2.5\ \text{k}\Omega + \frac{12.5\ \text{k}\Omega}{7.5\ \text{k}\Omega}$$

$$= 2.5\ \text{k}\Omega + 1.6\ \text{k}\Omega$$

$$= 4.1\ \text{k}\Omega$$

This effective resistance of the circuit is then used to determine the voltage applied to the second potentiometer which can be found by using the ratio

$$\frac{\text{Input voltage}}{\text{Total effective resistance}} = \frac{\text{X(voltage applied to second potentiometer}}{\text{Effective resistance of } R_s + R_2}$$

$$\frac{10\ \text{V}}{4.1\ \text{k}\Omega} = \frac{X}{1.6\ \text{k}\Omega}$$

$$(X)\ (4.1\ \text{k}\Omega) = 16\ \text{k}\Omega$$

$$X = 3.9\ \text{V}$$

This 3.9 volts is applied to R_s. The slider of R_s is at its center of travel (50 percent). The voltage out (E_0) from R_s equals

$$E_o = E_{in} \chi\, \theta$$
$$= 3.9 \chi\, 0.5$$
$$= 1.95\ \text{V}$$

To eliminate the error in the output due to loading, the two potentiometers are isolated from each other with a network box and a feedback (isolation) amplifier, shown in figure 6-51. With the loading effect eliminated, the output is an accurate 2.5 volts. This is due to the fact that R_2 is no longer in parallel with R_s, but is in parallel with the input to the network box.

If the potentiometers are ganged together, as shown in figure 6-52, and the mechanical input is designated as the X input, then the output is equal to $E_{in}X^3$. Thus, potentiometers may be used to raise the power of an input (X). If a fourth potentiometer is used, the variable X is raised to the fourth power, and so on, by adding potentiometers.

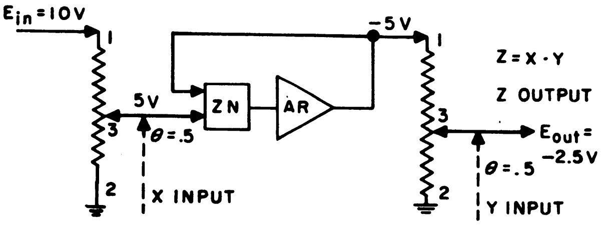

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Figure 6-51.—Elimination of loading effect for accurate multiplication.

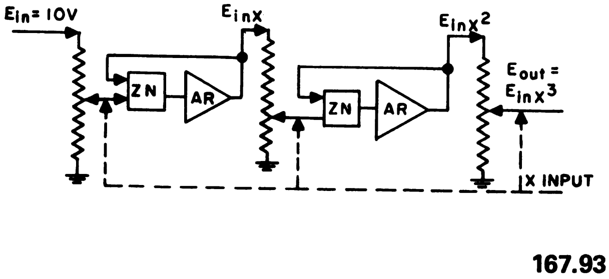

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Figure 6-52.—Powers by successive multiplication.

DIVISION WITH POTENTIOMETERS

Potentiometers can be used to perform division as well as multiplication. When two potentiometers are used for multiplication, the output is taken from the slider of the second potentiometer. To perform division, the output from the slider is fed back as a nulling voltage to the network box. The equation solved is $Z = X/Y$.

There are two facts known about the elements in a divider loop; a potentiometer is a multiplier, and a two-legged network box has equal knowledge (not necessarily equal voltage) on each leg. In addition to these two known facts, for the loop to perform division, the input-output ratio of the amplifier must be variable.

Looking at figure 6-53A, there are two variables in the circuit. The first is the input voltage into the network box (X input); the second is the amount of voltage fed back to the network box (determined by the Y input). The output of the loop is unknown, and is called Z. Potentiometer R_1 is supplied with a voltage, in this problem 10 volts. The slider is moved through an angle $X = .5$ or 50 percent, and the output from the slider is 5 volts. R_2 is supplied with the amplifier output (Z) and the slider is moved through an angle which is the Y input. Potentiometer R_2 actually multiplies the input voltage (Z) by the position of its slider (Y), and the output voltage (ZY) is the other input to the network box. If the output of the network box is theoretically zero, then

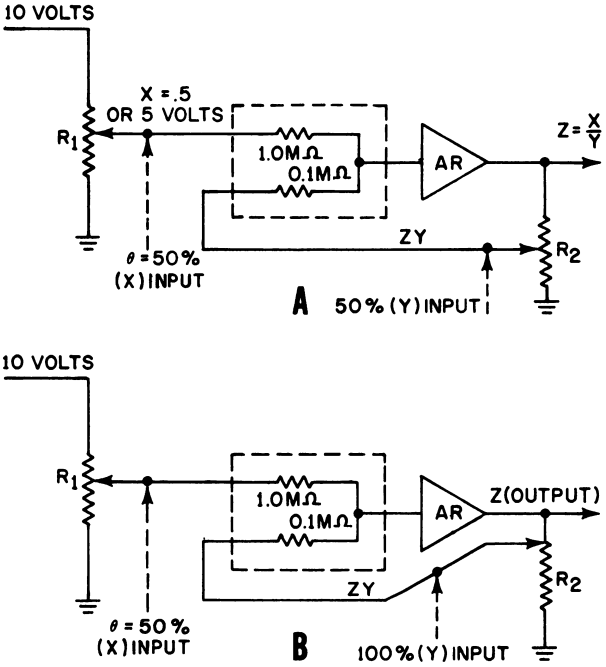

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Figure 6-53.—A. Divider loop using potentiometers; B. Divider loop operation.

$$0 = X - ZY$$

or,

$$ZY = X$$

then,

$$Z = \frac{X}{Y}$$

Taking into consideration the ratio of the network box resistances, the output is

$$Z = \left(\frac{R_f}{R_s}\right)\frac{X \text{ voltage}}{Y \text{ voltage}}$$

Due to the ratio (R_f/R_s) of the network box and the X input, only 0.5 volt is required to null the 5 volts input to the network box. This can be shown by moving the slider of the potentiometer R_2 to 100 percent of its travel. Then, the output of the amplifier is fed directly to the feedback leg of the network box. This is shown in figure 6-53B. The problem then becomes

$$Z = \left(\frac{R_f}{R_s}\right)\frac{X \text{ voltage}}{Y \text{ voltage}}$$

$$= \frac{.1}{1} \times \frac{5}{1}$$

$$= 0.5 \text{ V}$$

As long as the input remains 5 volts, the feedback voltage will be 0.5 volt. But, the output of the amplifier will vary as the Y input is changed, picking off a portion of the amplifier output.

Therefore, the gain of the amplifier is variable depending on the position of the slider of R_2. However, if the 5 volts input is changed, the amount of feedback voltage required to null this change will vary accordingly. For example, if the X input voltage were changed to 8 volts (representing X = .8), the amount of feedback required to null this voltage would be .8 volt.

$$E_f = E_s \frac{R_f}{R_s}$$

$$= 8 \frac{.1}{1}$$

$$= .8 \text{ V}$$

Taking the reciprocal of a quantity (fig. 6-54) is also a division process. In a reciprocal circuit, the input to the network box is a constant voltage (computer reference), and the slider of the potentiometer is moved by the mechanical input Y. The voltage output of the amplifier is the electrical reciprocal of the mechanical input, providing the slider is positioned at the top of the potentiometer for maximum input, and near ground potential for minimum input.

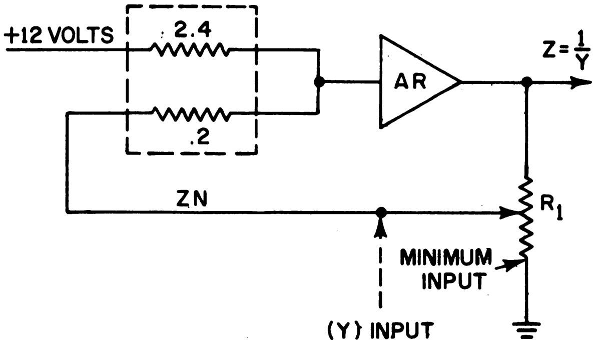

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Figure 6-54.—Basic reciprocal loop using a linear potentiometer.

SERVO MULTIPLIER

The servo multiplier is used to multiply two voltages together with the output as a voltage. The principle of operation is to first convert one of the voltages to a proportional mechanical displacement or rotation by using a servo. This mechanical quantity moves the slider of a ganged potentiometer to perform the final multiplication. A servo multiplier is illustrated in figure 6-55.

The two voltages to be multiplied are designated E_1 and E_2. Each of these voltages represents a computer variable. Through servo action, the servomotor positions the slider of potentiometer R1A so that the feedback voltage to the network box is always proportional to the input voltage E_1. Bear in mind that the feedback voltage, E_f, can represent several input voltages to the network box. Because potentiometer R1A is linear, the output angle θ is proportional to the input voltage E_1.

Now, let us assign values to voltages E_1 and E_3. Look at figure 6-55. If E_3 is a constant -12 volts and E_1 is +6 volts, the servo will drive until the slider of potentiometer R1A provides -6 volts of feedback to the network box. At this time, the servomechanism stops driving and the slider of potentiometer R1A is at 50 percent of a full rotation. Since potentiometers R1A and R1B are ganged together, the slider of R1B is also at 50 percent of a full rotation. Potentiometer R1A has provided the feedback voltage to position its slider correctly, and the multiplication will be performed by the potentiometer R1B.

If a value of 8 volts is assigned as the input voltage to potentiometer R1B, the output

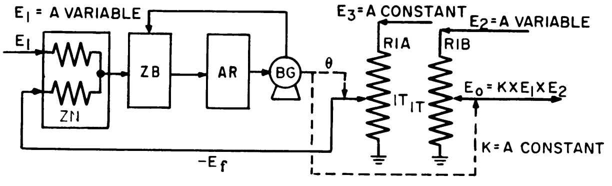

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Figure 6-55.—Volts χ volts multiplication with a servo multiplier.

voltage of the servo multiplier can be determined. Two values concerning the potentiometer are known: first, the slider is positioned at 50 percent of full rotation, and second, the input voltage is 8 volts. Thus, the equation $E_o = E_2 \chi$ percent of rotation can be used to find the output voltage. For this example, E_o is 4 volts.

The output voltage can be computed mathematically by using the formula assigned to the output of potentiometer R1B. The formula is

$$E_o = K \chi E_1 \chi E_2$$

The constant K will always be the reciprocal of the E_3 voltage applied to the feedback or nulling potentiometer R1A. The constant for this example is 1/12. Therefore, $E_o = 1/12 \chi 6 \chi 8$, or 4 volts.

By assigning scale factors to the servomultiplier (fig. 6-56), any rate χ time problem can be solved. The scale factors assigned below are for a target capable of traveling at a maximum speed of 810 knots. The computer reference voltage is 12 volts, and the maximum limit of time is 30 seconds. The problem is to convert a 6-volt input, with a scale factor of 2.5 seconds per volt, to a mechanical position and multiply this position by a rate expressed in yards per second per volt. The rate, 540 knots is represented by the 8-volt input to potentiometer R1B, and has a scale factor of 38.0025 yards per second per volt. The output voltage will therefore represent yards (yards per second χ seconds = yards).

The servomechanism will position itself so that potentiometer R1A provides a -6 volt feedback to the network box to null the input signal of +6 volts. This position represents 15 seconds, and potentiometers R1A and R1B are positioned at 50 percent of a full rotation (6 V at 2.5 s/V = 15 s).

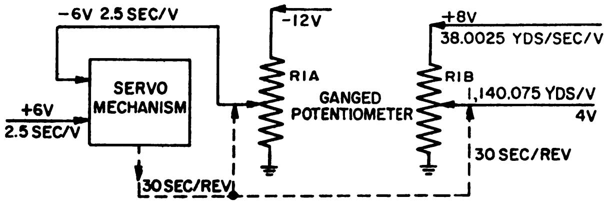

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Figure 6-56.—Servo multiplier with assigned scale factors.

Potentiometer R1B will perform the multiplication of 15 seconds χ 8 volts at 38.0025 yards per second per volt ($8 \chi 38.0025 = 304.02$); thus, multiplying yards per second χ seconds = yards ($304.02 \chi 15 = 4{,}560.3$). The results can be checked by dividing the yardage by the electrical scale factor of the output voltage. Thus,

$$\frac{4{,}560.3 \text{ yd}}{1{,}140.075 \text{ yd/V}} = 4 \text{ V}$$

TRIGONOMETRIC FUNCTIONS IN ANALOG COMPUTERS

In electrical analog computers, a.c. resolvers are used primarily for the solution of right triangles and coordinate rotation. In the solution of a particular problem in a computer, the resolver must be used in conjunction with a network box and feedback amplifier. In many cases, the output of a resolver will be the input to other resolvers, until as many as six or seven are connected into a resolver chain. Resolvers are low impedance elements. Therefore, to compute accurately, they must be isolated from the preceding element to prevent loading. Isolation is provided by a network box and feedback amplifier. The amplifier is sometimes called an isolation or booster amplifier. It has a low output impedance and can correct any undesirable phase shift developed in the resolver. Thus, in actual application, resolvers are connected in what may be referred to as basic resolver loops.

BASIC RESOLVER LOOP

Figure 6-57 shows a circuit diagram of a basic resolver loop. The input voltages are designated as Ea and Eb. The voltages are in phase or 180° out of phase with the computer reference voltage. The input voltages impressed on the stator windings of a resolver are always

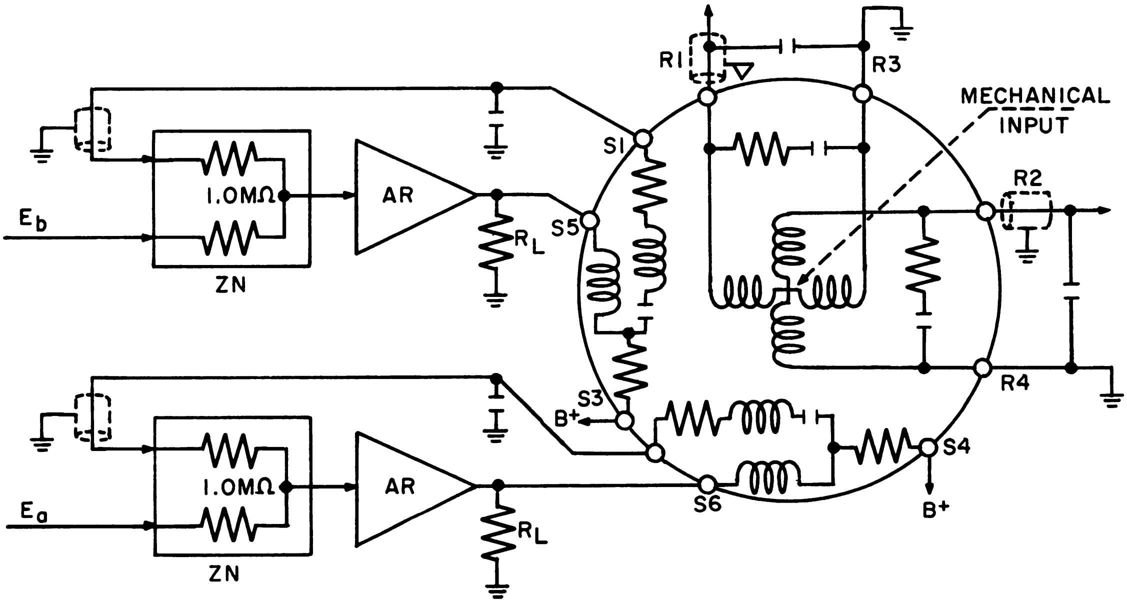

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Figure 6-57.—Basic resolver loop.

via a network box and isolation amplifier. Signal flow in the stator circuit is somewhat different than that of a sign reversing or summing computing loop. In those loops, the amplifier output is fed directly back to the network box as the feedback voltage. However, in a resolver loop the output of the amplifier is the input voltage to the stator winding of the resolver, which induces a voltage in an additional winding called the feedback winding. The voltage induced in the feedback winding is fed back to the network box as the feedback voltage, which must be out of phase with the input voltage to the network box.

The magnitude of the amplifier output is less than the input voltage to the network box, and a slight phase shift is designed into the loop to compensate for the phase shift developed in the resolver. There is a slight step-up of voltage between stator and rotor so that unity gain is achieved between the input of the loop (at the network box) and the output. In addition, to help achieve the unity gain desired and resolver interchangeability, the feedback and output leads are trimmed with a capacitor to provide a constant value of capacitance (up to 2,000 picofarads (pF) in some computers). These leads are coaxial cables and naturally have a certain capacitance per foot; therefore, trimming is necessary so that the various lengths of cables are made uniform in capacitance. The shields of the coaxial leads are grounded.

The amplifier output is also connected to a load resistor for proper operation of the amplifier. The load resistor may be mounted within the network box or mounted externally.

When the voltage at Eb is zero and the Ea voltage is of some nominal magnitude, the voltage induced in the R1-R3 winding will be equal to the Ea voltage and of the same phase, providing the rotor is at its zero position. At this zero position of the rotor, zero volts will be induced in the R2-R4 winding.

Clockwise rotation of the rotor will cause a voltage to be induced in the R2 winding that is out of phase with the Ea voltage. Counterclockwise rotation of the rotor will cause a voltage to be induced in the R2 winding that is in phase with the Ea voltage. When the rotor is at a position so that these conditions are met, the resolver is said to be on electrical zero.

Once the electrical zero position of a resolver has been set, trigonometric problems involving resolution, composition, and coordinate rotation can be solved by the resolver. To solve problems, the voltages induced in the rotor windings follow an established equation depending on the polarity of the Ea and Eb inputs, the rotor lead selected, and the direction of rotation of the rotor. For example, assume that Ea and Eb are +8 volts, and the rotor is rotated 30° clockwise. The voltages induced in rotor leads R1 and R2 are determined in the following manner (negative values determined by phase comparison).

$$R1 = EaCos\ 30^\circ + EbSin\ 30^\circ$$

$$8(.866) + 8(.5)$$

$$6.928 + 4$$

$$10.928\ V$$

$$R2 = EaSin\ 30^\circ + EbCos\ 30^\circ$$

$$-8(.5) + 8(.866)$$

$$-4 + 6.928$$

$$+\ 2.928\ V$$

For the same Ea and Eb inputs, rotation of the rotor counterclockwise a total of 30° will cause different voltages to be induced in R1 and R2. The voltages induced are determined in the following manner.

$$R1 = EaCos\ 30^\circ - EbSin\ 30^\circ$$

$$8(.866) - 8(.5)$$

$$6.928 - 4$$

$$+2.928\ V$$

$$R2 = EaSin\ 30^\circ + EbCos\ 30^\circ$$

$$8(.5) + 8(.866)$$

$$4 + 6.928$$

$$10.928\ V$$

Compare these voltages with those obtained when the rotor was rotated clockwise:

ROTATION OF ROTOR	R1 OUTPUT	R2 OUTPUT
cw	+10.928 V	+ 2.928 V
ccw	+ 2.928 V	+10.928 V

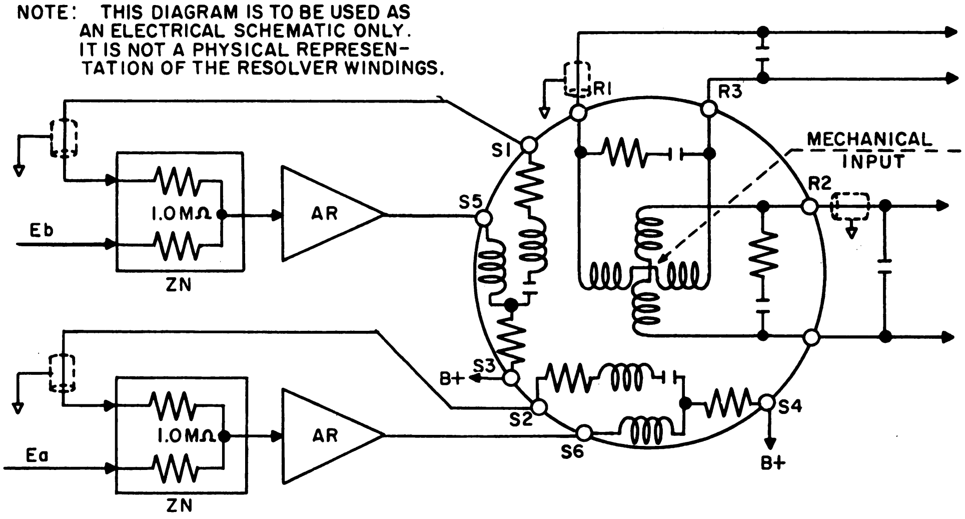
From the preceding comparison, it can be seen that the direction of rotation of the rotor has a very important bearing on the output voltages obtained. The preceding problems used a plus value of Ea and Eb. If either or both were negative, the outputs would naturally change.

The table in figure 6-58 shows the various combinations of output voltages available from a resolver under different conditions. The second and third columns indicate the condition of the rotor connections: HIGH meaning the output lead, LOW SIDE meaning the rotor lead is grounded. The next column shows the direction of the rotor from electrical zero. The next four columns show the output functions in relation to the polarity of the Ea and Eb inputs.

To illustrate use of the table, consider the preceding example where the rotor was rotated counterclockwise. Both Ea and Eb were positive and the R1 and R2 windings were the outputs. Under the HIGH column, locate the two lines where R1 is high (lines 1 and 5). The ROTATION column is used next to determine which of the two lines to use. In this case, since the rotor was turned counterclockwise, use line 5. To read the output function from the R1 rotor lead, locate the OUTPUT FUNCTION listed in the +Ea +Eb column. This reads $EaCos\theta - EbSin\theta$, which is the same output function used to compute the R1 voltage in the preceding example.

The OUTPUT FUNCTION of the R2 winding would be read on line 7 under the same output function column. This line reads $EaSin\theta + EbCos\theta$, which is the same output function used in the original example.

When only one stator is energized, the input voltage will be applied as the Ea input. Therefore, only the Ea side of the equation is used; the Eb portion is deleted.


NOTE: THIS DIAGRAM IS TO BE USED AS AN ELECTRICAL SCHEMATIC ONLY. IT IS NOT A PHYSICAL REPRESENTATION OF THE RESOLVER WINDINGS.

	HIGH	LOW SIDE	ROTATION	OUTPUT FUNCTIONS			
				+Ea +Eb	+Ea -Eb	-Ea -Eb	-Ea + Eb
1	R1	R3	CW	EaCosθ+EbSinθ	EaCosθ-EbSinθ	-EaCosθ-EbSinθ	-EaCosθ+EbSinθ
2	R3	R1	CW	-EaCosθ-EbSinθ	-EaCosθ+EbSinθ	EaCosθ+EbSinθ	EaCosθ-EbSinθ
3	R2	R4	CW	-EaSinθ+EbCosθ	-EaSinθ-EbCosθ	EaSinθ-EbCosθ	EaSinθ+EbCosθ
4	R4	R2	CW	EaSinθ-EbCosθ	EaSinθ+EbCosθ	-EaSinθ+EbCosθ	-EaSinθ-EbCosθ
5	R1	R3	CCW	EaCosθ-EbSinθ	EaCosθ+EbSinθ	-EaCosθ+EbSinθ	-EaCosθ-EbSinθ
6	R3	R1	CCW	-EaCosθ+EbSinθ	-EaCosθ-EbSinθ	EaCosθ-EbSinθ	EaCosθ+EbSinθ
7	R2	R4	CCW	EaSinθ+EbCosθ	EaSinθ-EbCosθ	-EaSinθ-EbCosθ	-EaSinθ+EbCosθ
8	R4	R2	CCW	-EaSinθ-EbCosθ	-EaSinθ+EbCosθ	EaSinθ+EbCosθ	EaSinθ-EbCosθ

167.99

Figure 6-58.—Standards for resolver Mk 4 Mod 3.

PRACTICAL APPLICATION OF THE BASIC RESOLVER LOOP

The basic equations for resolvers used in this example (fig. 6-59) are

$$R1 = XSin\theta + YCos\theta$$

$$R2 = XCos\theta - YSin\theta$$

The outputs are not the actual phase of the output voltage, but merely indicate that the induced voltages will add or subtract when the rotor is in the first quadrant. To produce the above equations, stator windings S1 and S2 are supplied with a positive voltage (positive with respect to ground at the resolver, not the input to the amplifier), and the resolver rotor is rotated clockwise for an increasing quantity. Notice how the rotor is rotated in relation to the stator windings. This will be helpful when you actually phase out a resolver loop. When a resolver is replaced, the loop must be adjusted to provide unity gain between the input to the loop and the output. Two adjustments are involved—the phase and the gain adjustments.

The basic objective is to adjust the loop so that the output voltage of the rotor has the same

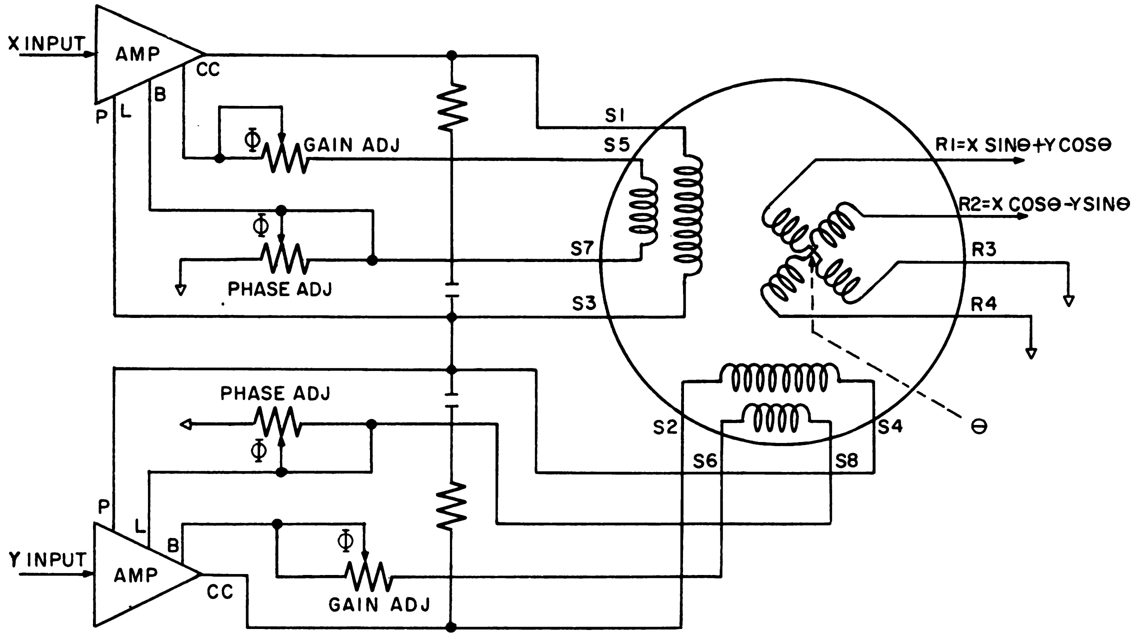


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Figure 6-59.—Basic resolver loop—practical application.

phase and amplitude as the input voltage to the amplifier when the rotor is at its zero position.

At the zero position of the rotor, the winding concerned is parallel to the stator winding that is inducing the voltage in it. In this position, there should be unity gain, or one-to-one transformation, between the input to the amplifier and the resolver output, and a zero phase shift should take place. If unity gain or the desired phase shift is not achieved, then the phase and gain adjustments must be made so that the amplifier output is changed in both phase and magnitude to provide the proper output from the resolver.

Figure 6-60 illustrates the connections for making the gain and phase adjustments for the X point. The Y input is grounded, and all grounds shown must be common. The Lissajous pattern on the oscilloscope should make a diagonal figure eight, compressed in height as much as possible.

RESOLUTION

One of the trigonometric functions a resolver is capable of handling is the resolution of a vector. This is the process of taking a vector in its polar form and resolving it into its two rectangular components. To accomplish resolution with a resolver, one electrical input and one mechanical input are required. Two electrical outputs will be obtained.

Two resolvers can be used to resolve present target position (a vector in polar form) into three voltages representing target position in Cartesian (rectangular) coordinates. Figure 6-61 shows the geometry of the problem and figure 6-62 is a schematic diagram of a typical resolver chain that changes (transforms) polar coordinates into rectangular coordinates.

The electrical input to resolver BR-1 is range R. The rotor is mechanically positioned by target elevation E. The output from rotor lead R4 is target height Rv or the Z axis of a rectangular coordinate system. This is one of the electrical quantities desired. The output obtained from rotor lead R3 is horizontal range Rh. Thus the rectangular components (Rh and Rv) of the vector, represented by R (its magnitude) and E (its direction), have been determined.

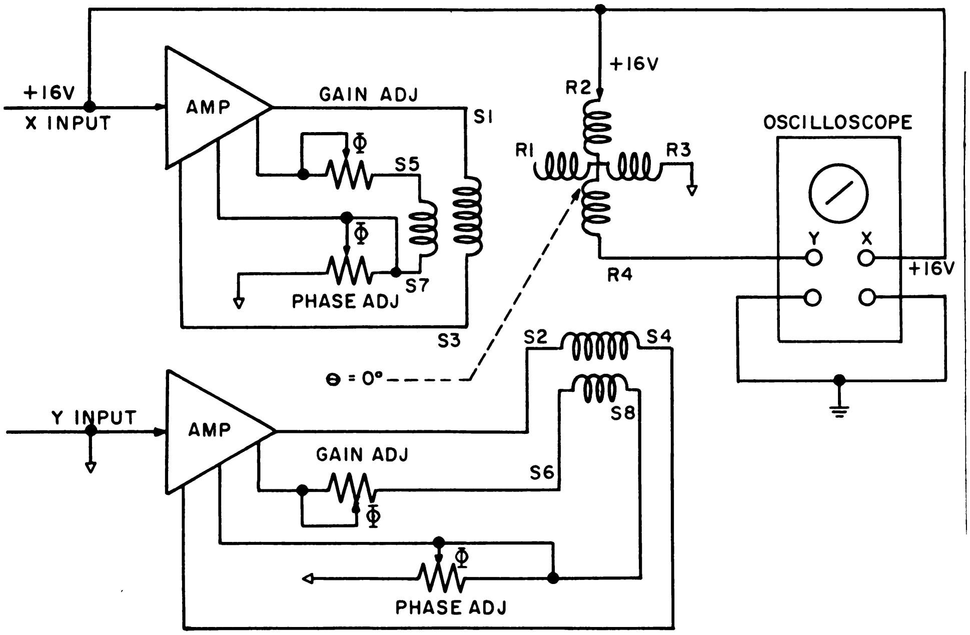

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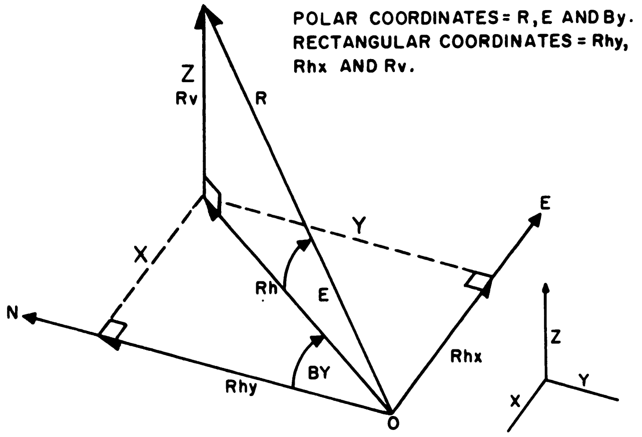
Figure 6-60.—Oscilloscope connections for adjusting phase and gain of a resolver loop.

Horizontal range Rh (it can be thought of as the length of a new vector lying in the horizontal plane) is the electrical input to resolver BR-2. The rotor is mechanically positioned by true target bearing By (the direction of vector Rh). The output from rotor lead R3 is north-south horizontal range Rhy or the Y axis of a rectangular coordinate system. The output from rotor lead R4 is east-west horizontal range Rhx (the X axis). The outputs are the two quantities (X and Y) required to express present target position in Cartesian coordinates.


POLAR COORDINATES = R, E AND By.
RECTANGULAR COORDINATES = Rhy, Rhx AND Rv.
Z
Rv
R
X
Y
E
Rh
E
N
BY
Rhy
Rhx
O
Z
Y
X

167.102

Figure 6-61.—Defining the position of a point in space by rectangular and polar coordinate systems.

Resolver BR-1 solves the following equations: R CosE = Rh and R SinE = Rv. Resolver BR-2 solves the following equations: Rh CosBy = Rhy and Rh SinBy = Rhx.

COMPOSITION

Another trigonometric function a resolver handles is the composition of a vector. This is the process of taking a vector in its rectangular form and composing the vector in its polar form. In other words, two sides of a right triangle are known and the resolver solves for the hypotenuse and acute angle. To accomplish composition with a resolver, both stator windings are energized. These inputs represent the height and base of the triangle. One

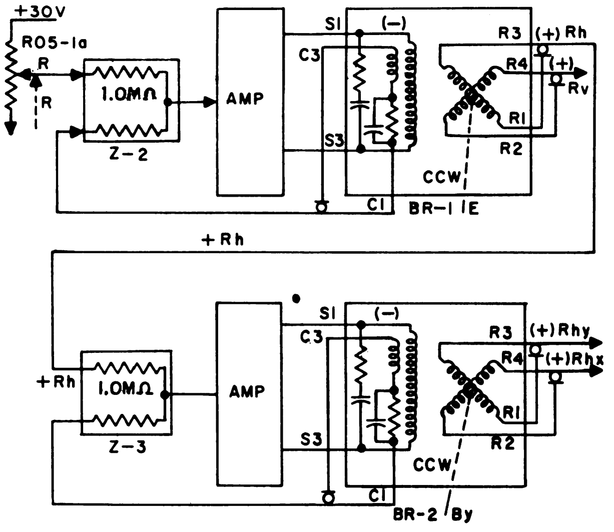


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Figure 6-62.–Typical resolver chain for converting polar coordinates into rectangular (Cartesian) coordinates.

electrical output and one mechanical output will be obtained. These outputs represent the hypotenuse and acute angle. To obtain a mechanical output from a resolver, one rotor winding provides the input signal to a servomechanism which drives the rotor of the resolver until zero volts is induced in the winding. When this operation is complete the resolver loop has composed the vector. The position of one rotor represents the angle of the vector and the other rotor output represents its magnitude.

The loop diagrammed in figure 6-63 is used to change rectangular coordinates of target motion to a vector quantity, thus representing target course (direction) and speed (magnitude). The two motion coordinates, DMhy and DMhx, are computed with respect to the north-south axis and the east-west axis, respectively. A resolver is used to compose these coordinates into a vector which has target course Ct as its direction and target speed DMh as its magnitude. Figure 6-64 shows the geometry of the problem.

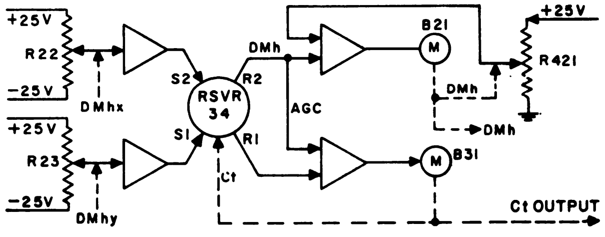

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Figure 6-63.–Vector composition.

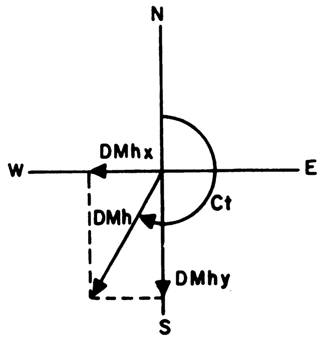

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Figure 6-64.–Geometry of rectangular to polar transformation (the composition of vector components).

Returning to figure 6-63, potentiometers R22 and R23 are energized with +25 and -25 volts, since target rates (DMhx and DMhy) will be either plus or minus quantities. A target course of zero degrees is computed when the output of R22 is zero volts and R23 has a negative output.

To compute a target course of 45°, assume that the output of potentiometers R22 and R23 is -15 volts. Servomotor B31 will drive the rotor of resolver 34 counterclockwise until a null voltage is induced in the R1 winding. Concurrently, the voltage induced in the R2 winding will be a maximum negative voltage, or -21.21 volts.

To provide the above outputs, the voltages induced in R1 and R2 must follow an established equation in each rotor winding. These equations are

$$R1 = -DMhx (Cos Ct) + DMhy (Sin Ct)$$

$$R2 = -DMhx (Sin Ct) - DMhy (Cos Ct)$$

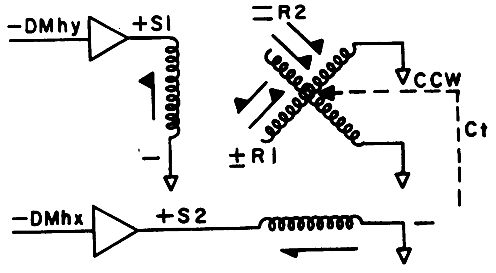

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Figure 6-65.—Polarity of rotor windings (R1 and R2) of B34.

The voltages induced in R1 (fig. 6-65) will subtract; therefore, the mechanical position of the rotor represents the angle of the target course vector. The voltage induced in R2 will add; therefore, the magnitude of the R2 voltage represents target speed DMh. A servomechanism is used to obtain a mechanical representation of target speed. Automatic gain control is provided to the Ct servomechanism so that the gain of the amplifier varies inversely with the target speed.

Another trigonometric function a resolver can handle is the rotation of coordinates. This process involves the rotation of rectangular coordinates from one axis system to another axis system.

To rotate coordinates from one axis system to another, a resolver must have one mechanical input and two electrical inputs. Two electrical outputs are obtained.

The geometry of a coordinate rotation problem is illustrated in figure 6-66. Target position is expressed by rectangular coordinates Rhx and Rhy. These quantities relate how far the target is from ownship, measured along the north-south axis and the east-west axis. The problem is to express target position in rectangular coordinates with respect to the centerline of ownship; or, in other words, to determine the distance to the target along and perpendicular to ownship centerline. Actually, the quantities desired are the rectangular coordinates of the relative target bearing vector. The quantities Rhx, Rhy, and Cqo are given in figure 6-66.

To solve the two equations, Rh CosB = Rhy (CosCqo) + Rhx(SinCqo) and Rh SinB = Rhx (CosCqo) - Rhy (SinCqo), two resolvers are used. (See fig. 6-67.) Horizontal range Rh and true target bearing By are the inputs to resolver B1 which resolve the polar vector into rectangular coordinates, Rhx and Rhy. The equations solved by resolver B1 are: Rhx = Rh SinBy and Rhy = Rh CosBy. The magnitudes of Rhx and Rhy are +8.66 volts and +5 volts, respectively.

The rotor of resolver B2 is rotated by ship's heading Cqo, and the stators are energized by Rhx and Rhy—stator S5 by Rhx and S6 by Rhy. If ship's heading were 0°, resolver B2 would compute the rectangular coordinates of the polar vector; that is, the R1 output would be +5 volts and the R2 output would be +8.66 volts. However, ship's heading is 20°; therefore, the R1 output will increase while the R2 output will decrease. The equations solved by resolver B2 are

$$R1 = Rhy(CosCqo) + Rhx(SinCqo)$$

$$5\ V(.9397) + 8.66\ V(.342)$$

$$4.70\ V + 2.96\ V$$

$$+\ 7.66\ V$$

$$R2 = Rhx(CosCqo) - Rhy(SinCqo)$$

$$8.66\ V(.9397) - 5\ V(.342)$$

$$8.14\ V - 1.71\ V$$

$$+\ 6.43\ V$$

The R1 and R2 voltages are the rectangular coordinates of the relative target bearing vector Rh and B, and are measured along and perpendicular to ownship centerline. Hence, the R1 voltage represents Rh CosB, and the R2 voltage represents Rh SinB.

INVERSE SINE AND COSINE LOOPS

A resolver can be used in a loop to solve for an angle, given the sine or cosine of that angle.

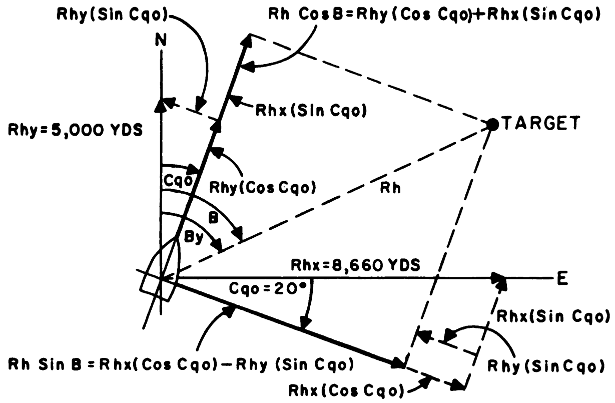

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Figure 6-66.–Geometry of a coordinate rotation problem.

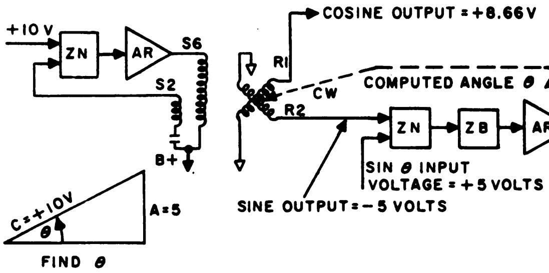

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Figure 6-68.–Inverse sine resolver loop.

Such a loop is shown in figure 6-68, and consists of a resolver, a network box, and a servomechanism.

In this loop the rotor of the resolver is driven by the servomechanism whose mechanical output is the computed angle θ. If the R_2 voltage is not equal and of opposite phase to the Sin θ input voltage, a signal to the servomechanism will cause it to drive the rotor until it becomes equal.

Since the resolver stator is supplied with a constant voltage, the R2 voltage is at all times proportional to the sine of the computed angle; that is, R2 = 10 volts χ sine of the computed angle. The R1 voltage is at all times proportional to the cosine of the computed angle; that is, R1 = 10 volts χ cosine of the computed angle.

In other words, the resolver loop solves for angle θ when the hypotenuse (10 volts) and the height (Sin θ input voltage) are known. Assume that the Sin θ input voltage is +5 volts and that the resolver is energized by a constant +10 volts. The servomechanism will drive the rotor until the output of R2 is -5 volts, at which time the loop will stop driving. The resolver rotor must be rotated clockwise through a 30° angle to produce this output. The R1 output at this position of the rotor is +8.66 volts. If the Sin θ input voltage were changed to 3.42 volts, the

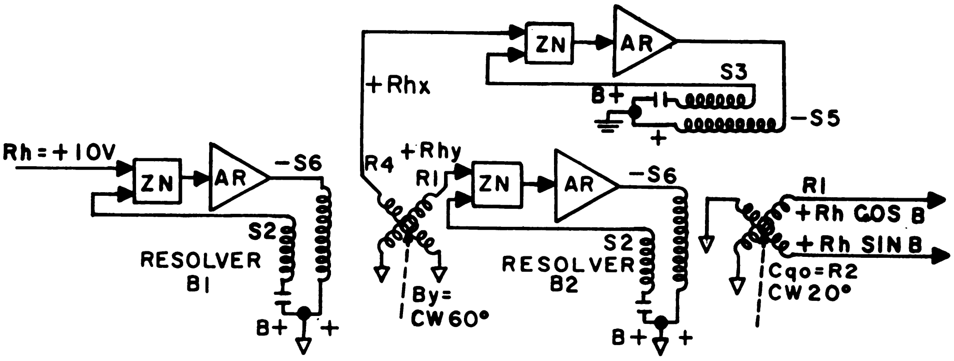

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Figure 6-67.–Rotation of rectangular coordinates with resolvers.

resolver would solve a 20° angle. If the Sin θ input voltage were -8.192 volts, the resolver would solve a 55° angle.

The resolver loop can be made to function as an inverse cosine loop by selecting the rotor lead R1 as the input to the network box. By necessity, the other input to the network box would have to be a voltage that represents the cosine of the angle desired. The inverse cosine loop is shown in figure 6-69. Operation of the loop is the same as that discussed for the inverse sine loop, except the two known parts of the triangle to be solved are now the hypotenuse and adjacent side.

If the Cos θ input voltage were -8.66 volts, the resolver loop would solve a 30° angle. The R2 output voltage would be -5 volts. If the Cos θ input voltage were -9.397 volts, the resolver loop would solve a 20° angle, and the R2 output would solve a 50° angle. The R2 output would be -7.660 volts.

Note that only one stator winding of the resolver was energized in either loop. Thus, the hypotenuse of the triangle was represented by the input voltage to the resolver.

RATE COMPUTING LOOPS OF ANALOG COMPUTERS

In an analog computer, a rate computing loop establishes the rate of change of its input, and compares the output against the input, thereby determining the acceleration or deceleration of the input. The mathematical process of obtaining the rate of change of a quantity is known as differentiation, and the result is the derivative. In an analog computer, the process is referred to as rate control; that is, when an error exists between the input and the established rate, the loop will correct the rate. In an analog computer using the Cartesian coordinate system, the rates of change of Rhx, Rhy, and Rv are determined so that the future target position can be predicted. The rates of change in Rhx, Rhy, and Rv are DMhx, DMhy, and DMv, respectively. Figure 6-70 shows a typical rate computing loop consisting of an a.c. servo, a d.c. tachometer, and a d.c. servo. The loop establishes the rate of change of position of a target along the east-west coordinate. Or, in fire control shorthand, the overall loop establishes DMhx. East-west horizontal range (Rhx) is the input to the a.c. servo-loop which converts the input voltage to an equivalent shaft rotation. The a.c. servo output rotates the rotor of a d.c. tachometer, which generates a d.c. voltage proportional to the rate of change of Rhx. This signal is passed through a smoothing network where any sudden changes in the d.c. level are filtered out. The smoothed d.c. voltage is then fed to the d.c. servo, which positions the slider of potentiometer R2. The voltage picked off the slider of R2 is fed back to cancel the d.c. input signal. When these two voltages are equal in amplitude and opposite in polarity, the servo stops driving. At this time (null) the position of the servo represents the linear rate—DMhx. Potentiometer R3 simply converts the mechanical position of DMhx into an a.c. signal for use in another section of the computer.

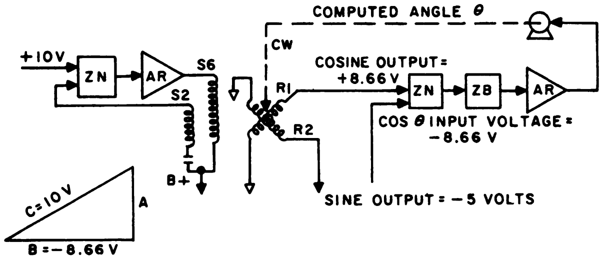

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Figure 6-69.—Inverse cosine resolver loop.

Since the target is constantly in motion, the Rhx input voltage will be changing. If the target maintains a steady course and speed or constant velocity, the Rhx voltage will change at a linear rate. The output of the d.c. tach in the a.c. servo loop will represent this linear rate by producing a constant d.c. voltage. So once the d.c. servo has established DMhx, the servo will not move until there is an increase or decrease in the rate at which the Rhx input is changing. This change will occur only when the target increases or decreases speed or changes course, or in other words, the target accelerates. When there is an increase or decrease in the rate at which the Rhx input voltage changes, the tachometer output will vary accordingly. The two d.c. inputs to the d.c. servo now have different amplitudes, and the servo drives to establish a new DMhx and provide a feedback voltage to cancel the tachometer voltage.

SUMMARY

The fundamental characteristic of an analog is its similarity to a designated object in some area; i.e., it duplicates the geometry, dynamic behavior, or some other aspect of the object. The basic operating principle of an analog computer is continuous measurement of quantities.

Analog computers can be employed in weapons and fire control systems wherever problems of calculations from continuous data, simulation, or control are encountered.

This continuous calculation requires that the fire control computer be designed for a particular system, which reduces its versatility. Fire control computers are not general purpose computers. Several quantities are continuously measured in the fire control system (such as range, bearing, and elevation of the target) and always applied to the same inputs of the analog computer. Inside the computer, the manipulations are continuously performed and the results are continuously available at the outputs, to be fed to the rest of the fire control system.

In the areas of target detection and tracking, analog computers are used to direct radars, store data on target location and velocity, and predict future target motion. The calculations necessary to direct the gun battery are performed by computers. In addition to actual operation of fire control systems, analog computers are used to simulate targets for training purposes, and evaluate the performance of fire control systems in engaging the simulated targets. The history of increasing complexity in fire control systems and the increasingly rapid pace of warfare, as well as improvements in the capabilities of computers, indicate a still greater dependence on computers in the future.

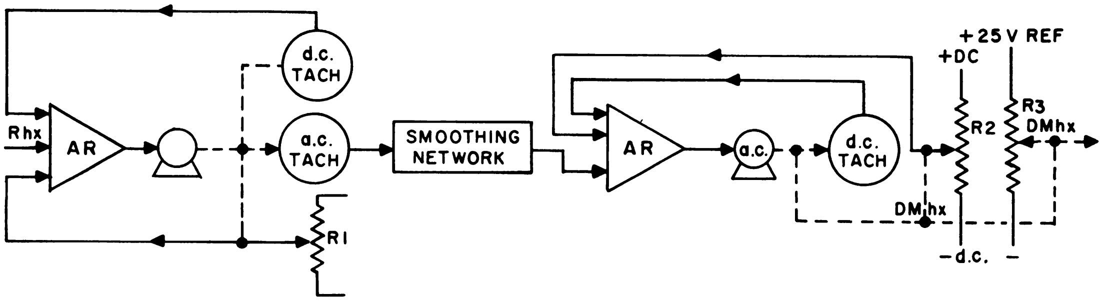

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Figure 6-70.—DMhx rate loop.

CHAPTER 7

FUNDAMENTALS OF DIGITAL COMPUTERS

Digital computers and other equipment based on digital techniques are becoming increasingly common in gun fire control systems. Due to current developments in electronics and in the fire control field, digital computer application is expanding. As a result, digital computers are gradually replacing analog computers (fig. 7-1). Consequently, as a fire control technician, you will find a number of electronic systems which use digital equipment as an integral part of the overall gun fire control system. In order to understand the operation of the fire control system in general, and the computer portion of the system in particular, it is necessary for you to have a basic understanding of digital computer functions, circuitry, terminology, and applications.

Numbering systems, logic functions, and arithmetic used in digital computers are not discussed in this chapter. It is assumed that you have already acquired this information from the

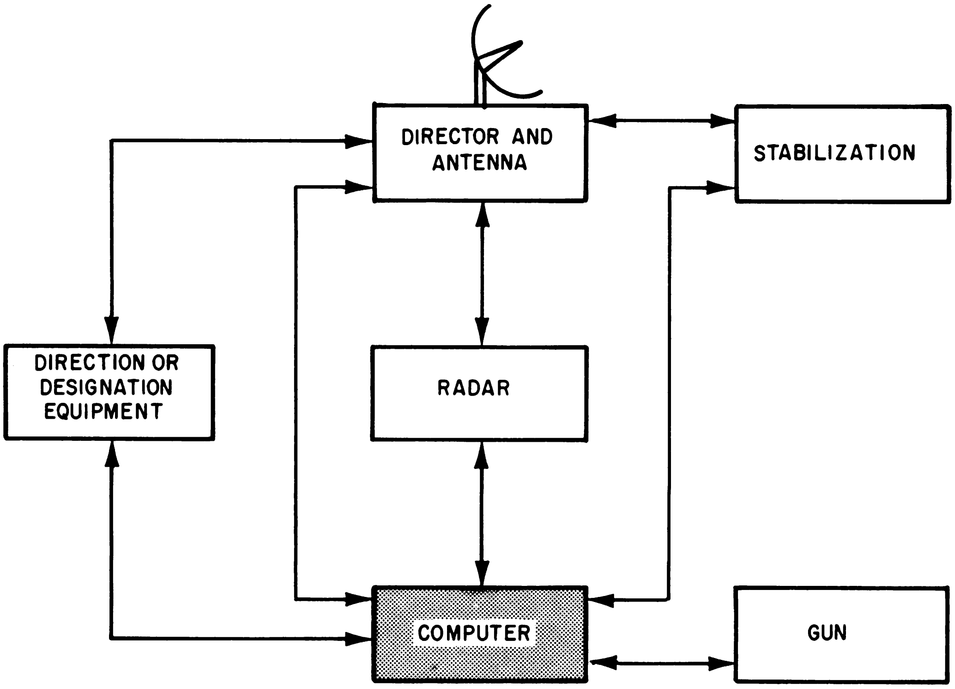

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Figure 7-1.—Digital computers are replacing analog computers in fire control systems.

NEETS module on the basics of digital computers, or *Digital Computer Basics,* NAVEDTRA 10088. The goal of this chapter is to furnish you with information that will provide a better understanding of digital computers as they are used in fire control systems.

DIGITAL VERSUS ANALOG

In contrast to analog devices, digital computers use discrete values to represent the digits 1 and 0. In addition, the computations are performed by electronic switches and circuits. A fundamental difference between the two types is that the analog computer is continuously presenting a solution to the problem, while the digital computer performs each computation separately. In other words, when one of the factors in a problem changes, the solution presented by the analog computer changes continuously as the inputs change. In a digital computer, the entire computation must be done again after each increment of change in the input.

Most computers used in fire control are part of control systems where time is a factor in the problem. The computer receives information from radar and other sources and makes decisions. The decisions are presented at the output of the computer to control some specific operation, such as providing a bearing or elevation angle to a gun mount.

Digital computers accomplish things that were impossible before, and they speed up processes which formerly required considerable time. Although the utilization of computers is not new, the new techniques of electronics have made it possible for a computer to be contained in a small, lightweight package which is adaptable to shipboard fire control systems. Also, prior to improvements in the electronics field (transistors, integrated circuits) the speed of operation required to solve the fire control problem was impossible to achieve.

The definition of a computer is: any device that is capable of accepting information, applying mathematical operations to that information, and obtaining useful results of those operations. Therefore, a computer must have an input section, a processing section, and an output section.

Before any problem can be solved by a computer, the quantities involved must be expressed in terms of common units; that is, digital computation is the process in which digits alone are used to solve the problem.

Basically, the purpose of a digital computer is the same as that of any other computational aid. However, it is more accurate than an analog computer within the practical limits of time (speed). Digital computers can perform thousands of repetitive computations involving hundreds of thousands of digits without making an error. Further, they can store millions of items of information for future use.

Simple and explicit instructions (programming) must be provided for each operation that is to be stored. How to use a quantity, what to do with a quantity, and what step is required next are sometimes more complicated than the problems the computer is used to solve.

Essentially, a digital computer collects data, performs a set of planned manipulations on the data, and provides an output of useful information from the contents of the data. The ability to calculate is built into a computer by proper combinations of simple circuits and components. It can retain information by storing it in memory banks, and it can accept instructions and data inputs in the form of a step-by-step procedure called a program. The program outlines the steps of the operation and the sequence of their occurrence. Computer programs are discussed later. First, the major functional units of a digital computer must be examined.

MAJOR FUNCTIONAL UNITS

A digital computer is made of basic circuits that are interconnected to form functional units.

Each unit has a relatively simple primary function, such as to compare and relate numerical values or to perform addition, subtraction, multiplication, or division upon numerical values. All digital computers can be broken down into five major units: input, control, memory, arithmetic, and output. A simple block diagram of a digital computer is shown in figure 7-2.

INPUT UNIT

For a computer to perform a specified series of operations, it must be fed both the instructions and the data to be used in the computations. Many different devices are used to properly present the information to the computer. Some examples are the modified electric typewriter, the punched card and punched tape reader, the magnetic tape reader, and a variety of manual input devices, such as pushbuttons and toggle switches. In fire control applications, the most common input device is the analog-to-digital converter, which changes the analog voltages and currents into the digital form required by the numbering system used in digital computers.

CONTROL AND ARITHMETIC UNITS

The control unit of a computer ties all parts of the computer together, causing them to function as an integrated system. Its functions are the same as for the control unit of any system. It exercises complete control over every operation the computer performs.

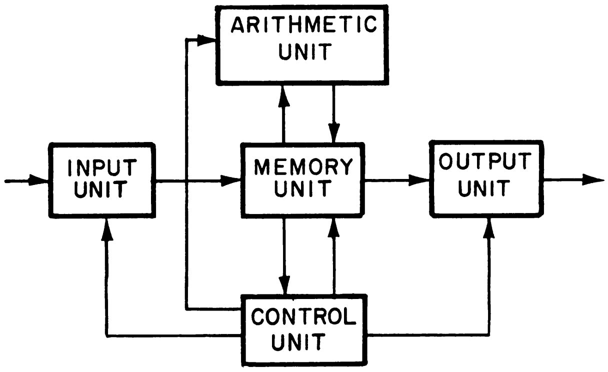

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Figure 7-2.—Fundamental units of a digital computer.

The arithmetic unit is the calculating unit. It contains circuits that are simple in both theory and operation. It performs mathematical operations—addition, subtraction, multiplication, and division—by performing logical operations. It must be remembered that all mathematical calculations dealing with numbers take some form of one, or more, of these basic operations. For instance, squaring a number is merely a special form of multiplication; extracting a square root involves all four operations in a special order. Similarly, an exponential curve is simply the result of many instantaneous values computed by arithmetic means.

By comparing data quantities against each other, the arithmetic unit is able to make logical decisions. For example, it can determine the proper weapon line (angle) by considering target speed, wind velocity and direction, drift, ballistics information regarding the particular weapon, and other factors that have been fed to it. It can then provide a "yes or no" answer to specific questions. The solution to a given problem is sent from the arithmetic unit to the memory unit where it remains in storage until needed for further calculations, or until otherwise routed by the control unit.

MEMORY UNIT

The memory or storage section of the computer is used to store the information which is used during the computational process. It stores both the program instructions and the data used in the computation. The memory can be used to hold both intermediate and final results as the computer goes through the program. Common memory devices include magnetic cores, magnetic drums, magnetic tapes, ultrasonic delay lines, and flip-flops.

Figure 7-3 shows a magnetic core memory. Each core can be magnetically polarized to equal either a 1 or a 0. Therefore, each core can hold just one bit of data at a given time.

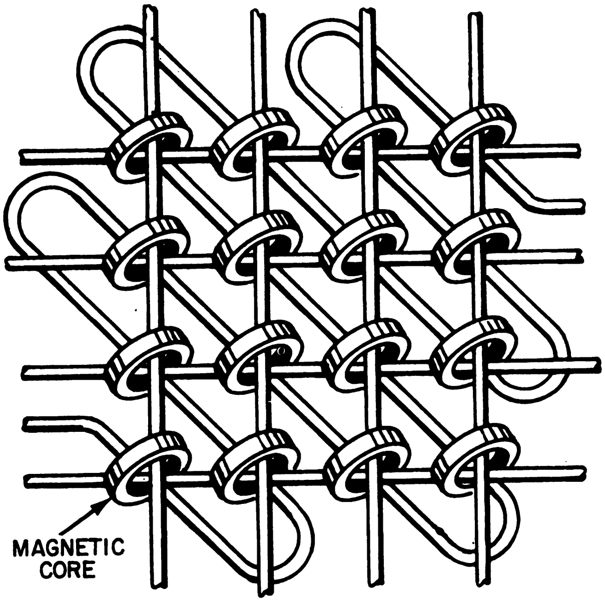

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Figure 7-3.—Magnetic core memory.

Regardless of the type of memory employed, it is divided into a number of locations, each of which is identified by an address. When the control unit calls for an instruction from the program or a piece of information which is stored in the memory, it acquires the information by using the proper address to establish the path to the appropriate memory location and the data stored there.

This type of accessibility is referred to as random or sequential access. The normal construction of storage devices makes any address accessible. However, the length of time required to obtain the information is determined by the type of storage device. Storage can be accomplished on tape, magnetic devices, or special circuits.

The information stored at each address is referred to as a "word." Each word is represented by a number of pulses or signal voltage levels. A word can represent either a numerical quantity or a computer instruction, but only one word can be stored in any given address.

In serial form, the individual instructions and information bits are fed step after step, one bit at a time. This is a comparatively slow process, but it can be accomplished with fewer and simpler circuits. Parallel input permits a number of bits to be fed at the same time, resulting in a much faster rate. More complex circuitry is required for parallel inputs. In a practical computer, instructions and information may be fed into the computer at the rate of 3 million bits per second, using the parallel input. Rates as high as 50,000 bits per second are common with serial feed systems.

The velocity of light is the maximum speed limit at which a digital computer can pass data from one unit to another.

A computer has two internal storage systems—the main storage in the memory unit and registers located in the arithmetic and the control units. Registers store the instruction or information necessary to accomplish a step (or steps) in a program. A register is referred to by its storage capacity in bits, an assigned letter designation, or by the function it performs, such as storage, shift, accumulator, or complement. Each register is capable of storing as many bits as it has flip-flops, and with its associated circuits, it can accomplish other functions. When a storage register is associated with a flip-flop counter circuit, it can convert from a serial form input to a parallel form input. A shift register can move the binary point of a stored word to the left or right. An accumulator register can store a word, then receive another word and produce their sum. A complement register can store the two's complement of the input word.

The memory unit can store all the instructions and information required to complete a complex problem, such as the fire control problem. Thus, all the formulas and the numerical values of the quantities in the problem are stored in memory so they are available when needed.

Memory Terms

The capacity of a memory device is measured by the amount of information in bits or binary decisions it can store. The capacity of a flip-flop is one bit, a register can store a word, while a magnetic tape or a matrix of magnetic cores can store many words.

Access time refers to the time required to write in information to storage or read out information from storage. This includes the time necessary to communicate with the storage location. Random access requires an equal amount of access time for any address. In other words, access time is independent of the storage address of the previous word. Access is said to be cyclic if the access time depends on the location of the address, as in the case of a rotating magnetic drum. With a magnetic drum, access time depends on the instantaneous drum position.

Destructive readout means the stored word is no longer contained in the storage device after readout. However, the "destroyed" word can be written back into the storage device before the access time is complete. Flip-flops and magnetic cores are destructive readout devices. Nondestructive readout means the stored word is not "destroyed" by the reading process. Magnetic tapes and punched cards are nondestructive readout devices.

Erasable storage is widely used in computers, since it is essential to be able to store different words at different times at the same address. To erase a word from a memory device is to "Clear" the device. Examples of erasable storage include magnetic cores and tapes. Examples of nonerasable storage devices are punch cards and tapes.

A "Set" pulse is used to change the state of a register from zero to one. A "Reset" pulse is used to change the state of a register from one to zero.

A nonvolatile storage device retains stored information during the absence of power. Examples of nonvolatile storage devices include magnetic cores, drums, and tapes. The stored information in a volatile storage device, such as a flip-flop, is lost or altered if the computer's power is interrupted.

OUTPUT UNIT

After the computer has done the computations, there must be some method of communicating the results to the operator. The devices used to "read out" the results are similar to those used in the input unit (punched cards or tape, magnetic tape, etc). Specialized output devices include audio or video displays and digital-to-analog converters.

RELATIONSHIP BETWEEN FUNCTIONAL UNITS

The interdependence of the functional units can be shown by solving a sample problem: $(3 + 8) \div (4 + 2)$. The problem is inserted into the computer using the following program:

1. Add the first pair of numbers and store the result.
2. Add the second pair of numbers and store the result.
3. Divide the result of step 1 by the result of step 2.
4. Write out the answer.
5. (3)
6. (8)
7. (4)
8. (2)

The first four parts of the program are instructions and the last four parts are the data to be used.

The control unit interprets the first instruction, sets the arithmetic unit for addition, transfers the numbers required (3 and 8) to the arithmetic unit, and transfers the result back to memory. The arithmetic unit then performs the addition. The memory unit supplies the necessary data on command from the control unit.

The second step is the same as the first step, except that the data is transferred from a different location.

The third instruction causes the control unit to set the arithmetic unit for division, and transfers the two intermediate results from the storage locations used earlier. The arithmetic unit performs the division.

The fourth instruction causes the control unit to transfer the answer to an output device.

Note that the digital computer solved the problem in the same manner as you would with a pencil and paper. Note, also, that the computer followed the program, step by step. If the computer is to solve a problem correctly, the program must be explicit. It should be realized that the computer does not manipulate real quantities according to physical laws. It does, however, manipulate symbols (digits), which represent the quantities, according to the fixed rules of arithmetic. Since digital computers deal entirely with numbers, a thorough knowledge of number systems is essential.

PROGRAMMING

A modern digital computer is capable of adding and subtracting almost indefinitely with lightning speed. Some can also make decisions based on the results of previous calculations. However, despite these capabilities, the computer cannot automatically perform its functions by itself. Each step of the problem that the computer is to solve must be worked out in advance by a "programmer." The programmer is the individual who decides how the problem should be worked by the computer and then writes the program which outlines the sequence of operational steps. These instructions are placed in the computer to activate the internal circuits so that the computer will process problems and provide solutions.

The programmer may not be concerned with the actual answer to the problem, but only with the fact that an answer is produced and placed in the memory unit at a specified address. The computer may be instructed to perform the same operation over and over. If any of the data changes, the solution also changes. The solution to one problem is often used in making other calculations required in the overall operation.

The programmer for a computer does not necessarily need to know the mechanical or electronic theory of a computer, but there is a need to know its maximum capabilities, such as the size of its memory and word length.

CONTROL

The switching or routing system of signals in computers can be compared to a huge railroad yard where many trains are being routed through a maze of tracks. All the trains are controlled from a central point and move as directed by a controller.

A train is formed by directing an engine to move through the maze of tracks in the yard, picking up one or more cars at designated points. The completed train then moves out of the yard as an integral unit. The paths followed in forming the train are predetermined and directed in sequence by the controller.

In a similar manner, the control unit of a computer is the controlling device that does the switching. The courses taken by the binary bits resemble the tracks of the yard. In the output of the computer, the completed data is analogous to the train.

THE PROGRAM

When making a program for a computer, the programmer determines the sequence of operations necessary to solve a problem. Many automatic functions are built into the computer, such as switching, counting, arithmetic operations, and others involving the special mechanics of arithmetic employed by computers. A program may be set up so that each operation is given a coded number designation. The programmer merely inserts the coded numbers as instructions to the computer. Programming is, technically, only one part of preparing a problem for solving by a computer. Actually, there are four major steps, as shown in figure 7-4. These are numerical analysis, flow charting, coding, and checking, and are frequently referred to collectively as "programming."

Numerical Analysis

Numerical analysis is the science (or the art) of reducing problems into terms, quantities, and

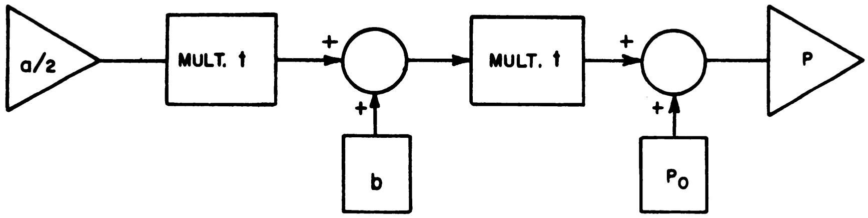
(A) NUMERICAL ANALYSIS

PROBLEM: DETERMINATION OF POSITION

$$P = at^2/2 + bt + P_0$$

a = ACCELERATION
b = VELOCITY
P_0 = POSITION AT $t = 0$
t = TIME

(B) FLOW CHARTING



(C) CODING

INST. NO.	INSTRUCTION
1	READ IN $a/2$
2	MULTIPLY BY t
3	ADD b
4	MULTIPLY BY t
5	ADD P_0
6	READ OUT

(D) CHECKING

INST. NO.	
1	$a/2$
2	$at/2$
3	$at/2 + b$
4	$at^2/2 + bt$
5	$at^2/2 + bt + P_0$

$$P = at^2/2 + bt + P_0$$

167.127

Figure 7-4.—A simple program for a digital computer.

equations that a digital computer can accept. In all but the simplest problems, extensive numerical analysis may be required before the program can be written. How does one represent an integral or differential, a cosine, or a quality? Numerical tricks, approximations, and even arbitrary values must be used in order to translate these concepts into the discrete numerical values required by the computer.

Flow Charting

Normally, problems are too long and too complex to encode directly from the mathematical analysis. Programming provides the shorthand, or guide, which makes it possible to translate the mathematical operations into the step-by-step operations required by the specific computer to be used. Programming is primarily the task of drawing flow charts, or block diagrams, and planning memory allocations.

A flow chart (illustrated in (B) of fig. 7-4) is essentially an annotated block diagram and is an organizational convenience. In addition to depicting the overall system logic, it shows the sequence of logic operations, the result of each choice, and the time and entrance point of all new data.

Although it is intended principally as an aid in writing the computer code, the flow chart is also an excellent troubleshooting and testing device. It has symbols to describe the various functions to be performed, to indicate a logical choice or optional sequence, and to show when a sequence is changed by new or modifying instructions.

Additional symbols and conventions are generally used to simplify the diagram and to make it a more complete instrument to aid in writing the code. These symbols are not standard, but they are usually consistent in a given set of charts. Their main purpose is to transfer information from the designer to the coder or other users of the computer.

Coding

Coding is the step-by-step transformation of the problem, as mapped out by the flow chart, into a final program written in the language of a particular computer. Coding is essentially a painstakingly precise bookkeeping operation. Each address, each digit, and every single command must be correct.

The coder, unlike the person who writes the flow chart, needs little knowledge of mathematics. It is not even necessary to understand computers. The only requirement is absolute adherence to the rules established by the design of the computer. Generally, in transferring from one type or model of computer to another, the coder must learn a new set of rules, a new computer language, or a new code.

Checking

Checking, or verifying, is the final step in what might be called the "training" of a computer. It is frequently performed automatically. The sole purpose of this step is to ensure that the coder has made no errors. The program prepared by the coder may be stored internally or externally. Storage is semipermanent or permanent, depending upon the purpose and application of the computer.

COMPUTER LANGUAGE

In the decimal number system, quantities are expressed using 10 digits, 0 through 9, in a system employing positional notation. Each digit represents a level of measure or a degree of quantity. Thus, a computer that uses the decimal number system must be able to distinguish the quantity each digit represents. Desk calculators and adding machines contain parts that have 10 possible positions or states corresponding to the 10 digits of the decimal number system.

The binary number system has a base of two and contains two digits, 0 and 1. Hence, these digits can represent only two possible states or positions. A computer can easily and accurately handle the quantitive aspects of these digits; either a digit is or it is not.

There are many components in the electrical/electronic field with a bistable condition. By this, it is meant that a component (relay, transistor, tube, etc.) either is passing current or it is not. Therefore, a computer using the binary number system does not require a well-characterized unit of energy to distinguish the quantity represented by a digit. The mere presence of an output voltage from a component can be used to represent the digit 1, while no output would represent 0. Because of its simplicity and high reliability, the binary system is used in the computer to represent data and bistable components are used to mechanize the data.

Any number that can be expressed in the decimal number system can also be expressed in the binary number system. The binary system uses a weight factor for the position of the digits in a number. The principle of positional value is the same as in the decimal system.

The octal number system, using digit 0 through 7, or base 8, number system, has certain advantages in computer work. It is used mainly to express long binary numbers in digital computer operation. In addition, the octal number system is used to check computer errors, which occur occasionally even in the best of machines.

WORD STRUCTURE

The language of digital computers is binary. The units (control, memory, etc.) of digital computers "talk" with one another in the same electrical language. Information and instructions are encoded into the presence or absence of electrical pulses. For example, the decimal symbol 3 is encoded in its binary form, 011, as: no pulse, pulse, pulse. Each pulse or no-pulse period is called a bit. A bit is a binary digit or symbol in the computer language. (Numbers, letters, and punctuation marks are other familiar examples of data symbols.)

Bits are arranged in groups to form a computer "word." To reduce the complexity of a computer and to ensure against ambiguity, each word consists of a fixed number of bits and has the same form. The number of bits in a word is designed into a computer; different computers may use different word lengths. Transfer and manipulation of data within the computer usually takes place using words.

Although all words have the same form, the information they contain is determined by the number and position of the bits containing pulses. Computer words can be divided into two basic groups: instruction (also called command) and information (also called data). Figure 7-5 shows each type of computer word and the significance of the bits. The computer shown has words with 19 bits.

Instruction Words

As the name implies, instruction words are orders to the computer to accomplish a particular operation. Instruction words contain address and no-address orders. An address describes the location of a word stored in the computer. Address orders require communication with the memory unit and can be divided into two main parts (fig. 7-5A). The first part, bits 1 through 5, is the code for the particular order; the second part, bits 7 through 18, is the memory address of the information word used in the execution of the order. Bits 0 and 6 of the instruction word are for special operations and are covered later. For now, let us continue.

Assume that a number located in register A is to be added to a number stored in memory. The first part of the word instructs the computer to add the number in register A to a number whose address in memory is contained in the second part of the instruction word. After the addition has been completed, the computer is ready for the next word. Incidentally, it takes the computer approximately 6 microseconds to accomplish this task.

No-address instruction words are divided into three parts (fig. 7-5B). The first part, bits 1 through 5, indicates that this is a no-address instruction word. The second part, bits 7 through 13, contains the code for a particular no-address order. The last part, bits 14 through 18, contains the information necessary to accomplish the order. In no-address words, bits

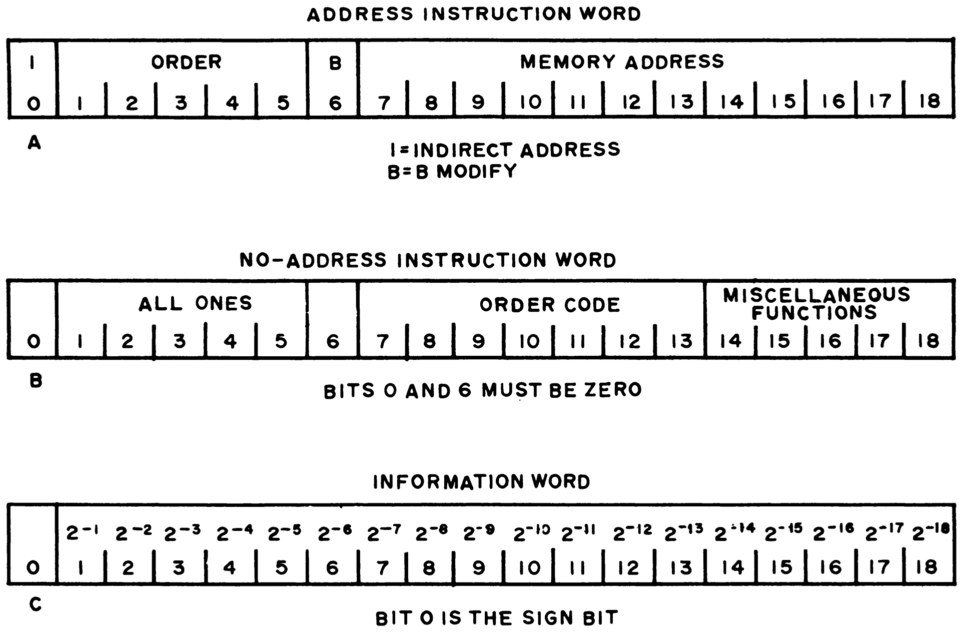


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Figure 7-5.—Word structure.

0 and 6 must be 0's. Let's consider an application.

Assume that we wish the computer to shift a number so many places to the left. When the number is shifted, the digits are moved right or left and their positional value is changed. A shift to the left increases the positional value of the digits. This is the same as moving the binary point to the right. For example, when the binary number 001100.000 is shifted three places to the left, it becomes 001100000.

As shown in figure 7-5B, the bits in the first part of a no-address instruction word are all ones. This identifies the word as a no-address instruction. The second part of the word instructs the computer to set itself up to shift a number to the left. The third part of the word indicates how many places the number should be moved.

Information Words

Information words contain the numerical value of a quantity in the binary system. There are 19 bits in a word (fig. 7-5C). The first bit indicates the sign of the number represented by the remaining 18 bits. A binary 1 sign bit indicates negative values, while a binary 0 indicates positive values. Since there are 18 bits in an information word, it can represent a numerical value of 2 to the 18th power.

The binary point is fixed between the first bit and second bit of the word. Therefore, the computer calculates using fractional numbers. All numbers used internally are equal to or greater than -1, but always less than +1. Negative numbers are operated on in the two's complement form. The two's complement of a number is obtained by inverting all the bits and then adding 1 to the least significant bit.

Some computers have a floating binary point. That is, the binary point may be placed anywhere in the number. In a floating-point, 19-bit information word, the first bit is the sign bit. The following 13 bits, 1 through 13, represent the number with the binary point to the left of bit 13. The last 5 bits, 14 through 18, represent the power of two used to shift the binary point. Thus, the numerical value of the last 5 bits indicates the number of places the binary point is to be moved.

If the binary point is not fixed or established by a floating-point system, the operator must locate the correct place for the binary point. This is done in the same manner as when determining the placement of the decimal point when using a slide rule.

PROGRAM MODIFICATIONS

An address instruction word has two bits, 0 and 6, which can be used to alter the program sequence or to interrupt the program. Three types of program modifications are discussed here:

1. B-modifying
2. Indirect addressing
3. Trap or interrupt mode

The B-modifying technique is used to change the address portion of the instruction word by the contents of the B-register. B-modification occurs when bit 6 of an address instruction word is a binary one. Bits 7 through 18 of the B-register are then added to the address portion of the instruction word prior to the execution of the order. In other words, the original instruction from memory is then altered by the B-register before the order is performed.

As an example of a B-modifying operation, assume the computer program is to solve for target course and speed based on a resolution of target motion. Acting on its instructions, the computer has calculated a target speed and has stored it in the memory unit. Then, new target data is received and the computer has to refine its solution. The B-modifying code is used to obtain a new instruction word from memory. The new instruction deals with the refined solution and may order the computer to compare the two target speed solutions or to store the corrected target speed at a new address in memory.

The indirect address technique is used to alter the address of an instruction with the address of another instruction word from memory. The address portion of the instruction word from memory is then used in the execution of the order contained in the original instruction word. Indirect address is performed when bit 0 of an address instruction word is a binary one.

To clarify the indirect address technique, assume the original instruction word ordered the computer to read out target speed from an address in memory. But, the target speed solution has been refined and stored at a new address in memory. The indirect address technique orders the computer to go to the address of the latest target speed solution and read out this information.

The interrupt mode is used to interrupt the normal computer program to perform another program or routine, such as reading in new data. The order to enter the interrupt mode is a no-address instruction word. Entering the interrupt mode is conditional, since the computer cannot be interrupted during certain portions of the main program. When the computer is in the interrupt mode, the next order of the main program is stored in memory and the computer transfers to the interrupt program.

For example, assume the computer's main program is to solve for target course and speed using the available target data. During the main program however, new target data becomes available. At the earliest possible opportunity, the computer enters the interrupt mode and inserts the new data into the main program by a subroutine program. When a new target bearing is available, the subroutine program orders the computer to clear the former bearing information located in memory and write in the new bearing.

CODING OF INFORMATION

The input-output data of a computer does not always represent numerical values. Some data, although symbolized by the digits 0 and 1, may signify a word. An example of this is the no-address instruction word. When all the bits in the address portion are 1's, the computer interprets this as two words which are no-address. Thus, the computer has a code in which the digits may represent either numerical or alphabetical symbols.

As you know, in the binary number system the position of a digit indicates its numerical value; thus, 110 has a different value (6_{10}) than 011 (3_{10}). But, we are not restricted to using the pure binary positional values. Codes which assign different numerical values to the binary digits in a number have been developed for computer use.

If you understand the principles of computer coding, memorization of the codes is not necessary. Different computers seldom use the same code. For this reason, there are many different codes. When working with a specific computer, you will become so familiar with its code that memorization will be automatic.

Codes are normally named after their four lowest integral weights, such as 5, 3, 1, 1; 4, 2, 2, 1; 8, 4, 2, 1; and 6, 4, 2, 1. Computer codes can be divided into three categories:

1. Regularly weighted
2. Arbitrarily weighted
3. Nonweighted

(The weight of a digit expresses its relative importance in a number.)

Regularly Weighted Codes

In these codes the position of each digit has a regular weighting value just as in the decimal number system. These codes are formed according to a specific rule or formula. For example, 7, 4, 2, 1 is a regularly weighted code. The weighting values form a simple arithmetic series, which begins with 1 and increases regularly, plus one unit, plus two units, plus three units. The important point to remember about regularly weighted codes is that the weights are determined by some rule. If you know the rule, you can find the weighting value for any position.

Arbitrarily Weighted Codes

These codes also use weighting values, but have no rule for forming them. Consider a code in which the four weighting values are 4, 2, 2, 1. There is no formula for generating these values. Arbitrarily weighted codes are very practical, since they are not restricted by a mathematical sequence and can be designed to fit the needs of a particular computer.

Nonweighted Codes

These codes have no weighting values. Each coded group is defined so as to represent some quantity. The Roman numbering system is a nonweighted code.

Pure Binary Code

The pure binary code uses the power of 2 as a weighting value and is the binary number system pure and simple. It has been mentioned previously that electronic digital computers use bistable components, such as magnetic cores, flip-flops, and diodes, that function best with binary numbers. Thus, straight or pure binary coding provides a definite advantage.

While binary calculations are convenient for the computer's internal operation, its input and output must be able to "talk" our language. We understand the decimal number system best. Therefore, in order to bridge the two systems, two translation units are required. These provide for decimal-to-binary and binary-to-decimal conversions.

To reduce the difficulty of the translation and the complexity of the converter units, a binary-coded decimal digit or coded digit is used.

Binary-Coded Decimal Digit

Each decimal digit can be represented by four binary digits. Thus, we can express the decimal number 736 in binary digits by considering each digit in the number separately. For example:

Decimal	7	3	6
Binary	0111	0011	0110

Note that this number is not pure binary; it is, instead, a binary-coded decimal number. (The number 736 in pure binary is 1011100000.) The coded digits need not be spaced because it is known that each digit is composed of four bits. For easier reading, however, there is usually a space between each coded digit.

This notation possesses important advantages for computer applications. Any decimal number can be expressed in the binary-coded decimal system but only 10 different conversions are necessary—one for each decimal digit. Furthermore, the computer is designed to calculate with coded digits as its base unit, not each binary bit. Thus, although the computer never operates with anything but binary numbers, it is, in a practical sense, a decimal calculator.

Error Detecting Codes

A coded digit can contain as many binary bits as the computer is designed to handle. Many codes have five or seven bits in their coded digits. Although some of the bits are extra and require additional circuitry, the advantage of these codes is their error detecting ability. As you know, each decimal digit can be expressed by a four-bit coded digit. Any additional bit is excess. The extra bit is called the parity bit and is used to detect errors in the manipulation and transfer of coded digits.

For example, using five-bit coded digits based on the 7, 4, 2, 1 code, add the fifth bit in such a manner that there are always two 1's in each coded digit. In other words, if there is a single 1 in a coded digit, 0010 for example, then another 1 is added, making it 00101. On the other hand, if there are two 1's in the coded digit, such as 0110, then a zero is added to produce 01100. Thus, the 7, 4, 2, 1 code is converted to what is called the two-out-of-five code, where each coded digit contains two 1's. The computer runs a parity check after each operation. The parity check tests the coded digit to ensure it contains two 1's. When the coded digit does not have a parity, the computer indicates an error and stops the program.

COMPUTER TIMING

One of the most critical functions in the computer is the timing of the various operations. In a synchronous computer, all operations are controlled by a timing system. The fundamental unit of time in a computer is called clock or bit time. This is the time required for the computer to generate a bit. The timing system provides a positive means of distinguishing between bits. The confusion which would result if the timing were off and the computer interpreted the last bit of one word as the first bit of the next word, can easily be imagined. Obviously, a computer must have an accurate timing system.

Most computers use a very stable oscillator to produce a fixed basic frequency. The output of the oscillator is shaped into pulses, which are referred to as clock or bit pulses. For example, a computer, which has a timing frequency of 250,000 kilohertz (kHz) produces a bit pulse every 4 microseconds (μs).

Since the time required to perform some operations varies, the computer must have a way to indicate completion of each step in an instruction. For example, depending on the numbers involved, multiplication can take anywhere from 6 to 14 microseconds. Therefore, the execution of each step in an operation must identify the next step in a programmed sequence. After initiation, operation is self-directed and proceeds automatically to complete the instruction word.

DATA CONVERSION

Data conversion equipment converts digital data from one code to another, or converts from analog-to-digital (encoding), or from digital-to-analog (decoding).

The data transmission devices discussed in chapter 2 are, and will continue to be, useful devices for the transfer of information. But, if the fire control system to which you are assigned has a digital computer, it must have some means of converting a synchro voltage or mechanical input into digital language (binary

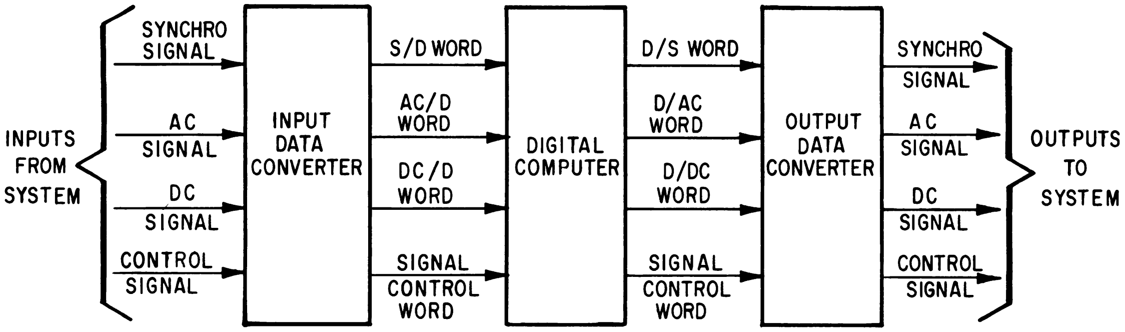

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Figure 7-6.—Signal data conversion.

data) for use by the computer. This is also true with the output information from a digital computer. The binary data must be converted back to a voltage or mechanical data transmission device. Figure 7-6 shows several different types of analog signals being converted to digital language for use by a digital computer, and then being converted back to analog signals for use by other instruments of the fire control system.

There are as many types of data converters as there are types of inputs (a.c., d.c., synchro, etc.) A few of them will be discussed to give you an understanding of how they operate. Each specific type of data converter is covered in detail in the appropriate OP for your fire control system.

ANALOG-TO-DIGITAL CONVERSION

An analog-to-digital converter is defined as a device that receives an analog input and supplies a digital output. A converter of this type is capable of accepting instantaneous values of a constantly changing variable and expressing these values in incremental or digital form.

The process of analog-to-digital conversions is not uncommon. Our minds make hundreds of analog-to-digital conversions each day. For example, if it were 4:30 and if you asked a young child what time it is, the child would probably look at a clock and tell you that the long hand is near the six and the short hand is near the four. The child is performing the function of data transmission, not data conversion. While accepting the instantaneous value of the constantly moving hands of the clock, the child, nonetheless, is transmitting the information in analog, not digital, form. The data which the child transmitted is converted into numerical values, in this case, 4:30. You, the inquirer, are, therefore, performing the analog-to-digital conversion; the child is not.

Care must be taken to avoid confusing authentic digital readouts with others that merely appear to be digital. The needle of a voltmeter or the pointer on an automobile speedometer provides analog data by indicating the instantaneous value of volts or miles per hour in a constantly changing manner. It is only by these meters and assigning numerical values that a truly digital readout is obtained. Just as in the example of the clock, the human observer is serving as the analog-to-digital converter. Similarly, the type of data that is obtained from a micrometer scale or from the mercury column of a thermometer is analog in nature, until converted by the reader.

On the other hand, mechanical counters such as those commonly used to count the number of people entering a building provide a true digital readout.

Mechanical Techniques

Probably the simplest method of converting analog information, such as shaft rotation, into digital form is the obvious one of connecting the shaft through a gear drive to a decade counter. This process is sometimes called shaft rotation digitation, since each rotation of the shaft is explained in digital form. One common application of the gear drive and counter method of conversion is used by the mileage counter (odometer) of an automobile.

This technique is also used in various other applications. Many airborne and shipbased analog computers used in bombing, navigation, or fire control applications, use this form of readout both for output indications and for an indication of input information that has been cranked in manually. Although this technique is simple and widely used, it is of rather limited value. It can be used for read-out or read-in purposes only. Since the digital output must be visually observed on the counter wheels, it cannot be used to feed another computer except through a human operator. In fact, this technique is not suitable for automatic operation.

SHAFT-POSITION DIGITATION BY GEARED COUNTER.–Shaft position digitation is defined as the process of converting and expressing the instantaneous position of a shaft in digital form. The simplest method of shaft-position digitation is similar to the technique that has been described in connection with shaft-rotation digitation. In the shaft rotation method, where the total number of revolutions or the function of the total number of revolutions is to be read out, a type of decade counter is used in order to obtain relatively high readings. For position indication, only a relatively small number of positions are required. It is therefore possible to use only one counter wheel containing as many digits as may be desired, each digit representing a definite rotary position of the shaft.

If the number of positions were very large, a type of decade counter would be helpful. The use of seven counter wheels could, theoretically, produce extremely fine readings, with a resolution as fine as 1 second of arc. Two of the wheels could be used to produce the readings from 00 to 60 seconds; the next two to the left could read from 00 to 60 minutes; and the last three, from 000 to 360 degrees.

Unfortunately, the similarities between this technique and the preceding one also reveal the limitations involved, since this method also provides only a read-out or read-in device.

SHAFT-POSITION DIGITATION BY MECHANICAL SWITCHING.–A device that is more useful than the previous devices, in at least one respect, can be devised by replacing the counter with a mechanical switching arrangement. Either cam-operated sensitive switches or a multipurpose rotary switch can be used. With this method, the output is electrical, although the device is basically mechanical. With each switch or tap feeding separate lines, the various output signals correspond to each separate shaft position. The signals can be used either as an input to some type of computing device or to feed numbered output lamps.

A disadvantage of this device is the physical limitation associated with the number of positions that can be read out. Each extra position requires the addition of another sensitive switch or the use of a larger rotary switch, plus another lamp. Although such a device might be practical for applications such as calling out 16 main points on a compass, any greater number of points would require the use of either an additional coding device or an entirely different technique.

Electrical Techniques

Two commonly used methods of performing analog-to-digital conversion by electrical means are the comparison method and the coding tube method.

COMPARISON METHOD.–The block diagram of figure 7-7 is used to illustrate the comparison method of determining the magnitude of the analog input.

Generally, the arm of the potentiometer is mechanically linked to the device which produces the analog signal. Some examples of this are the ship's pitometer (speedometer), the

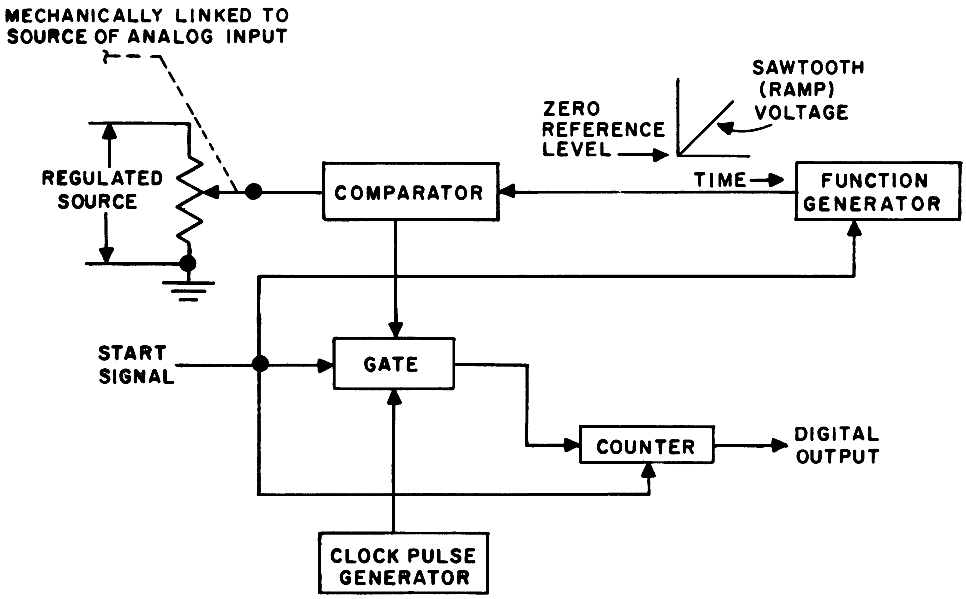

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Figure 7-7.—Determining the magnitude of an analog input using the comparison method.

director elevation, or the ship's master gyro. Used in this way, the potentiometer and the regulated source voltage combine to serve as a transducer which converts the mechanical input into an electrical output.

Because each position of the potentiometer arm produces a different value of voltage between its arm and ground, each position is unique in its content.

Two inputs are applied to the comparator in figure 7-7. These are: (1) the analog input from the potentiometer, and (2) a linear sawtooth voltage from the function generator. The function generator output is initiated each time a start signal is applied from the computer. The start signal also enables the gate circuit.

As long as the analog voltage and the function generator inputs to the comparator differ in magnitude, the clock pulse generator is permitted to transmit pulses at a constant repetition rate through the gate into the digital counting circuits in the counter. When the two inputs to the comparator become equal (as a result of the linearly rising sawtooth), the comparator generates a stop signal which disables the gate circuit and ends the comparison time interval. The disabled gate circuit blocks the flow of pulses from the clock pulse generator to the counter.

The number of pulses accumulated in the counter during the comparison time interval is proportional to the amplitude of the analog input voltage. The counter indication is the desired digital representation.

The clock pulse generator is a stable pulse oscillator. It may be a form of stabilized multivibrator. The counter may be an arrangement of flip-flops.

CODING TUBE METHOD.—The coding tube method uses a specially designed cathode-ray tube (fig. 7-8). The special features of the tube are in the form of a grid, which contains rows of coded slots, and a special sensing element.

The coding tube method of performing analog-to-digital conversion consists of the

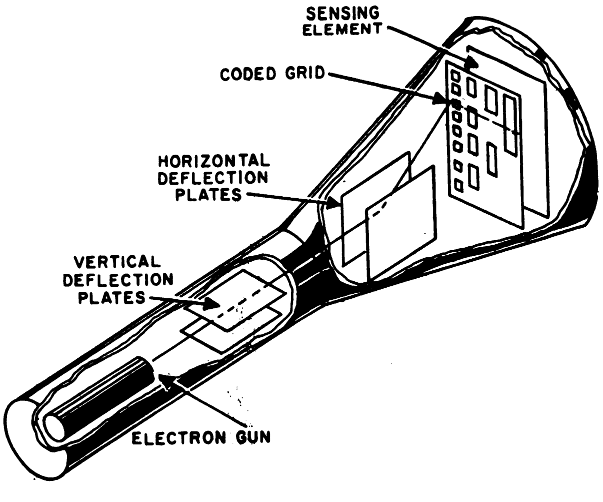

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Figure 7-8.—The cathode-ray tube.

following operations. The voltage that is to be converted is connected (after amplification) to the vertical deflection plates. A linear sawtooth sweep voltage is connected to the horizontal deflection plates. The connections to the vertical and horizontal deflection plates are not shown. The stream of electrons, which is emitted, focused, and accelerated by the electron gun, is positioned vertically on the grid so that it strikes a particular line of slots that correspond to the amplitude of the voltage to be converted.

The linear sawtooth voltage on the horizontal deflection plate causes the beam to be scanned across the line of slots. This action causes a coded image to be developed on the sensing element, which serves as the digital readout device.

High speed is the main advantage of the coding tube method of conversion. The disadvantages are that its accuracy is limited by the linearity of the scanning beam and by the beam diameter or spot size. The greater the spot size, the less reliable is the result.

DIGITAL-TO-ANALOG CONVERSION

Digital-to-analog conversion, like analog-to-digital conversion, can be accomplished by both mechanical and electrical methods. Let's first consider the mechanical method.

Mechanical Techniques

Mechanical digital-to-analog conversion is almost always based upon feedback and comparison principles. A representative example of this action is illustrated in figure 7-9. The digital input is fed into a comparator, which produces an input to a servoamplifier and servomotor combination. The servomotor is used to drive any of the many types of mechanical analog-to-digital converters. The digital output of the converter is fed back to the comparator, which operates as an error-detection circuit. As long as the digital output does not equal the input, an error signal will persist. This signal, in turn, causes the servomotor to continue to rotate until the error is reduced to zero.

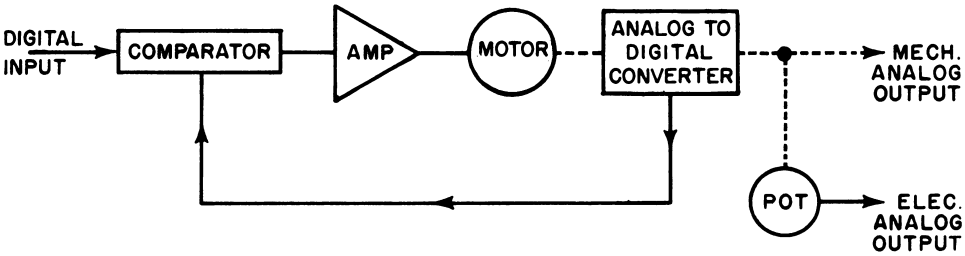

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Figure 7-9.—Block diagram of a mechanical digital-to-analog (d/a) converter.

The shaft or other mechanically driven device at the output of the analog-to-digital converter moves through a certain angle which is the analog representation of the digital input. When a transducer arrangement, which uses a potentiometer for readout purposes, is connected to the output shaft, an electrical signal that represents the same analog quantity is produced.

Electrical Techniques

Many electrical digital-to-analog converters operate on the principle of voltage division, using selective relays and a series-parallel network of precision resistors. One of the simplest circuit arrangements based on this principle is shown in figure 7-10.

NOTE: It is assumed that you have studied the *NEETS* modules concerning amplifiers and wave-generation circuits.

The binary (digital) input is fed into the bank of flip-flops. The 1 bits in each word stored in the flip-flops cause their respective relays to energize, which results in the closing of the associated contacts. Each of the resistors (R_1 through R_4) is a precision resistor. Assuming that each of the parallel branches conducts a given current value when its associated circuit switch is closed, it follows that the value of current through R_L is a function of the number of branches which are placed in the conducting state. If high accuracy is to be maintained, R_L must be kept small in comparison with resistors R_1, R_2, R_3, and R_4, even when these resistors are all connected in parallel. Because R_L is necessarily of low value, the output voltage (e_o across R_L) is low compared to the value of the input voltage (usually in the order of 1 volt). When higher output voltage levels or higher power output are required, the output voltage, e_o, can be amplified.

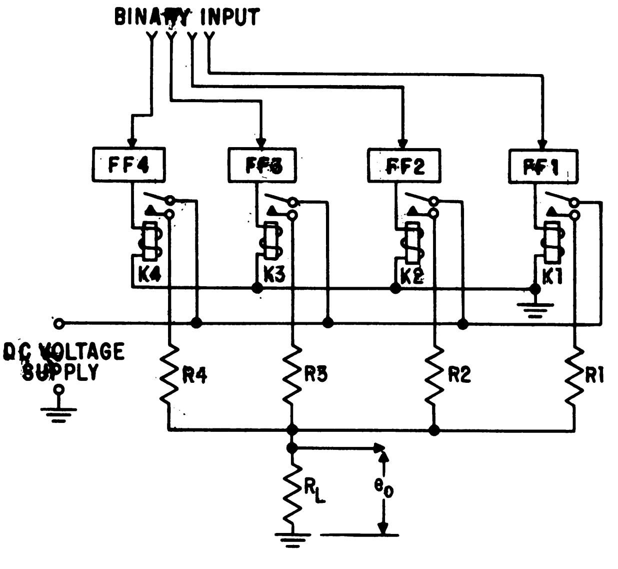

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Figure 7-10.—Digital-to-analog conversion using selective relays and voltage dividers.

A similar method of performing digital-to-analog conversion involves the use of a series arrangement of resistors connected in a feed-back loop of an operational amplifier circuit.

DIGITAL-TO-ANALOG CONVERSION USING THE SERIES RESISTOR METHOD.—The circuit in figure 7-11 contains a series array of resistors (R_1 through R_4) of selected sizes in the feedback loop of an operational amplifier. Each resistor is bypassed by a pair of relay contacts which represent 0 (or OFF) in the closed position and 1 (or ON) in the open position. When all of the contacts are closed, there is zero resistance in the feedback path, and the amplifier does not produce a voltage gain. When a 1 binary input is applied across any or all of the relay solenoids, the associated contacts open (as shown) causing resistance to be added to the feedback loop. The amount of increase in the amplifier gain is in direct proportion to the amount of resistance placed in the feedback loop by the opening of the relay contacts. The voltage, e_o, therefore represents the analog value of a digital input.

THE DIGITAL CIRCUIT.—A digilog circuit (sometimes called a decoder) is used to convert digital signals to analog voltages. In effect, it is a translator. It translates the language of digital devices (1's and 0's) into the language of analog

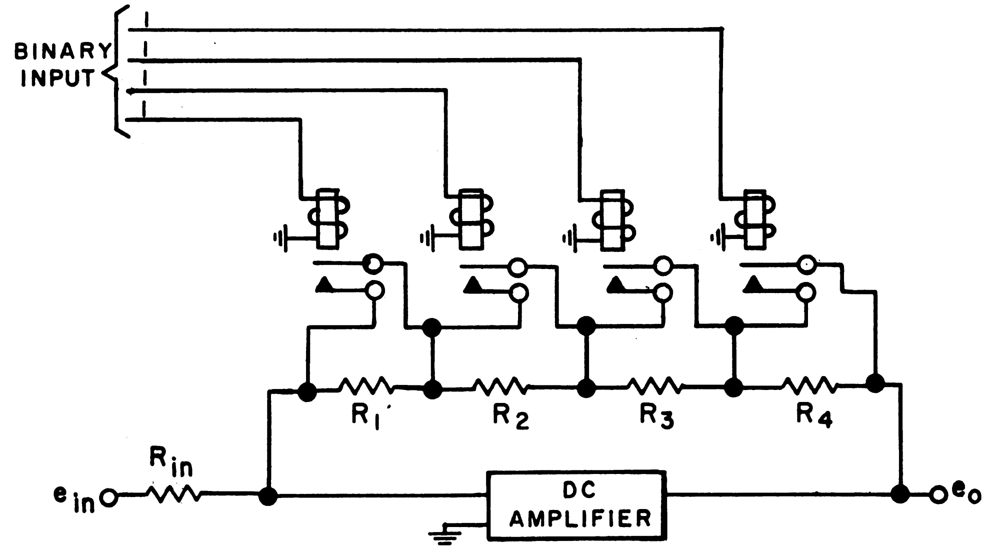

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Figure 7-11.—Digital-to-analog conversion using an operational amplifier and a series array of feedback resistors.

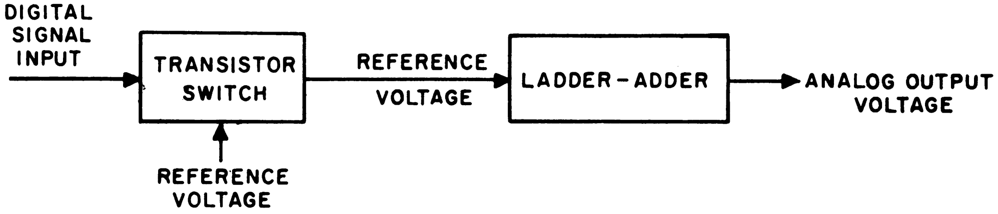

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Figure 7-12.—Block diagram of digilog action.

devices. These analog voltages are then used to position needles on meters, oscilloscopic sweeps, and/or dots on cathode-ray tubes, turn motor shafts, drive analog circuits, etc.

The digilog is composed of a bank of transistor switches and a resistive network known as a "ladder-adder." Figure 7-12 shows a block diagram of one transistor switch and the ladder-adder network. In an actual circuit where several digital inputs are received, a transistor switch is needed for each binary input digit. The transistor switches are opened and closed by the digital signal, allowing either a voltage or ground to be presented to the ladder-adder resistive network. The output of the ladder-adder is the required analog voltage.

Digilog Transistor Switches.—Digilog transistor switches are used to supply a voltage to the ladder-adder as determined by the binary value of the digit which controls each switch. There are, of course, many transistor circuit configurations which may be used to accomplish the switching. Generally, the digilog switching circuit will be similar to that shown in figure 7-13. This circuit uses a positive reference voltage, V_{ref}, as indicated at the emitter of Q1. By replacing Q1 with an npn transistor and Q2 with a pnp transistor, and properly biasing these

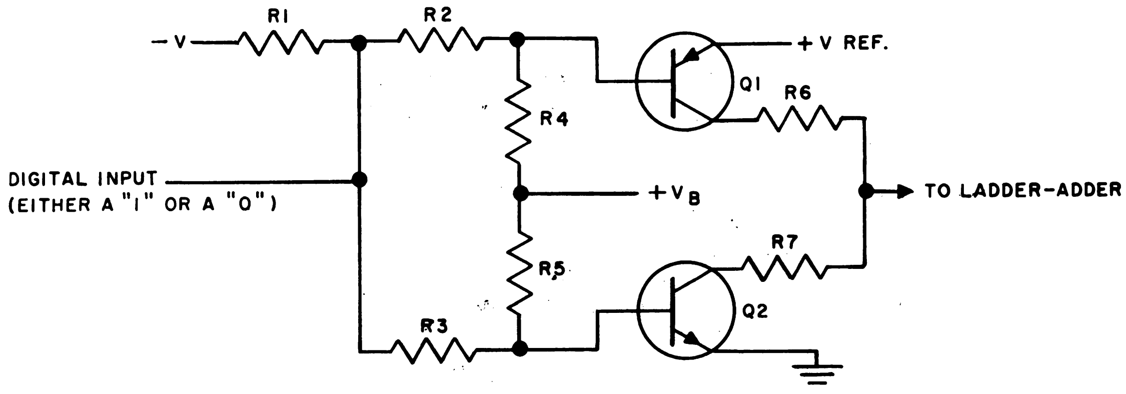

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Figure 7-13.—Digilog transistor switch.

transistors, a negative reference voltage can be switched into the ladder-adder.

As stated earlier, a transistor switch is needed for each binary input digit. For example, a 4-digit word requires 4 transistor switches and a 10-digit word requires 10 transistor switches. In figure 7-13, it is assumed that the true (-V) or "1" state is represented at the input and that the false or "0" input state is represented as 0 volts. With a true (-V) at the digital input terminal, Q1 conducts heavily and Q2 is cut off. Hence, the $+V_{ref}$ is supplied to the ladder-adder via the low conducting resistance of Q1 in series with R6. When the input is false (0 volts), Q1 is cut off and Q2 conducts, applying ground to the ladder-adder via the low conducting resistance of Q2 in series with R7.

The Ladder-Adder Resistive Network.—For purposes of explanation, four transistor switches and the corresponding ladder-adder network are illustrated in figure 7-14.

It is important to remember that in a practical application, the digilog can have as many transistor switches as desired with the associated ladder-adder network. A 4-switch digilog has 16 possible voltage levels as an output. This is so because the input can be either true or false (-V or 0) and there are four input switches. Hence, there are 2^4, or 16, possible input and output combinations. A 10-switch digilog has 2^{10} or 1024 possible output voltage levels. The greater the number of switches in the digilog, the smaller the incremental difference in the output voltage levels, as will be shown later. For simplification, the transistor switches have been replaced by toggle switches.

Certain basic requirements must be met with regard to relative resistance values and supply voltages in order to produce satisfactory results from the ladder-adder network. These are as follows: Resistors R3 = R5 = R7 and R1 = R2 = R4 = R6. A $+V_{ref}$ and $-V_{ref}$ of equal absolute value must be used. To aid in understanding the digilog, the following values are assigned:

A. R3, R5, R7 = 5 kohms

B. R1, R2, R4, R6 = 10 kohms

C. $+V_{ref} = +10$ volts

D. $-V_{ref} = -10$ volts

Table 7-1 shows the possible input conditions to the digilog switches, the corresponding position of each switch (either ground or a reference voltage), and the analog output voltage. A positive reference voltage is utilized for switches a, b, and c, and a negative reference voltage for switch d, so that the output voltage (V_0) can swing from a maximum positive voltage value through zero volts to a maximum negative voltage. In practice though,

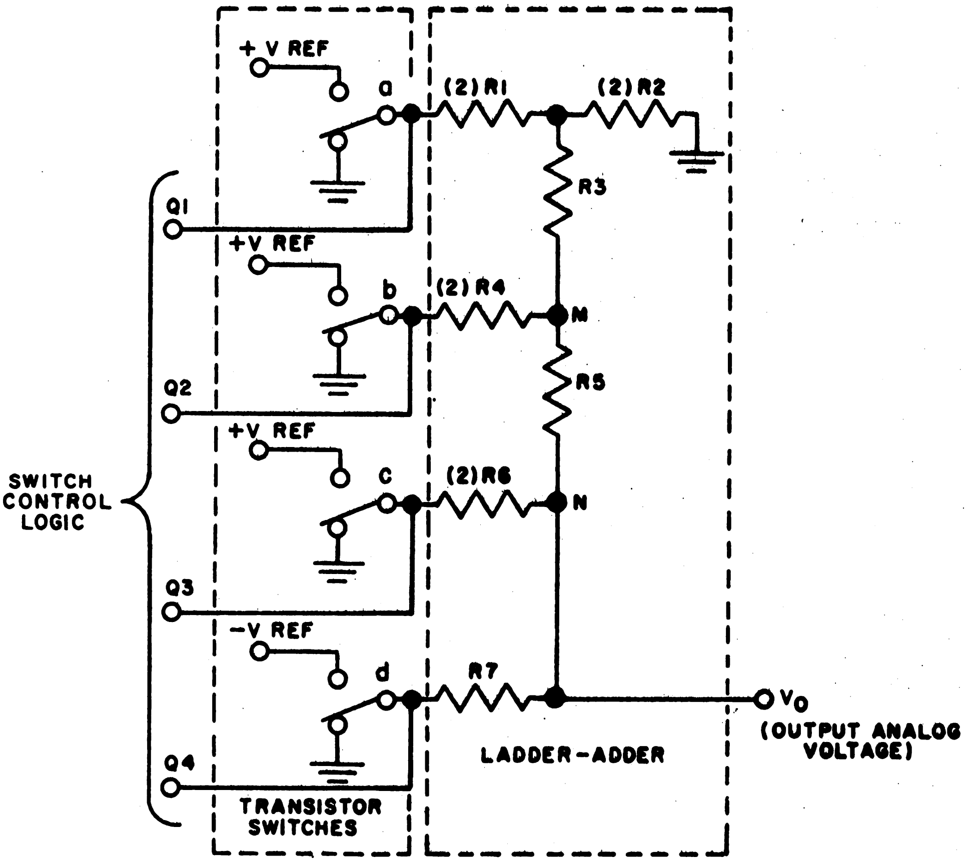

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Figure 7-14.—A four-digit digilog.

the digilog can be constructed to vary between any two voltage levels desired.

LINE DRIVERS AND INPUT AMPLIFIERS

In those cases where data is transmitted between equipment in digital form (electrical pulses), special circuits are used as line drivers and input amplifiers. The line driver circuits provide the signal power required to trigger the input amplifiers of the receiving equipment.

The input amplifiers receive their inputs from the line drivers of transmitting equipment. In many instances, the input amplifier must be gated by a gate signal before data is entered into the receiving equipment. In this manner, the flow of data between equipment is controlled.

COMPUTER TESTING

Computers can be given an overall check by means of special test programs. These programs provide a thorough and rapid method of checking the reliability and operation of the computer. The test programs present the computer with simulated data and instructions to manipulate the data. The results of the program are known; thus, the operation of the computer is tested against known output values. No special test equipment is required, since the computer circuits are used to perform the program.

Test programs that can be used to localize malfunctions in a computer are called diagnostic programs. An effective diagnostic program used

Table 7-1.—Input and output levels for four-digit digilog

Possible Switch Controlling Input Conditions				Switch Position Due To Input Conditions				Analog Output Voltage
Q4	Q3	Q2	Q1	d	c	b	a	V_0 (volts)
0	0	0	0	gnd	gnd	gnd	gnd	0
0	0	0	1	gnd	gnd	gnd	+ 10v	+ 0.625
0	0	1	0	gnd	gnd	+ 10v	gnd	+ 1.250
0	0	1	1	gnd	gnd	+ 10v	+ 10v	+ 1.875
0	1	0	0	gnd	+ 10v	gnd	gnd	+ 2.500
0	1	0	1	gnd	+ 10v	gnd	+ 10v	+ 3.125
0	1	1	0	gnd	+ 10v	+ 10v	gnd	+ 3.750
0	1	1	1	gnd	+ 10v	+ 10v	+ 10v	+ 4.375
1	0	0	0	-10v	gnd	gnd	gnd	- 5.000
1	0	0	1	-10v	gnd	gnd	+ 10v	- 4.375
1	0	1	0	-10v	gnd	+ 10v	gnd	- 3.750
1	0	1	1	-10v	gnd	+ 10v	+ 10v	- 3.125
1	1	0	0	-10v	+ 10v	gnd	gnd	- 2.500
1	1	0	1	-10v	+ 10v	gnd	+ 10v	- 1.875
1	1	1	0	-10v	+ 10v	+ 10v	gnd	- 1.250
1	1	1	1	-10v	+ 10v	+ 10v	+ 10v	- 0.625

124.274

in conjunction with maintenance diagrams and charts will locate the source of trouble to a particular area or circuit in the computer. A diagnostic program is usually made up of a group of routines, which, in turn, are composed of subroutines. Each routine tests a section or group of circuits of the computer, while the subroutines test all the operations performed by that section of the computer. For example, the control and arithmetic sections can be tested by directing the computer to perform the normal operations of addition or subtraction. When the results of a routine are not correct, the program stops the computer and indicates which subroutine failed.

The memory unit is tested by another routine in the program. This routine directs the memory unit to store a word represented under the worst possible conditions. That is, the worst possible data pattern is used. On the next alternate cycle of the computer timing system, the word's complement is stored. The data are then read and compared with a correct value. When an error is present, the program causes the computer to halt and the number of the memory address in the memory that failed is displayed. Each address in the memory unit is tested by the program. If the memory unit can store the test program words, it is assumed it can store words in a normal program.

Since a fire control computer is an integral part of a system, the diagnostic program must include a test of the data transmission circuits, since they affect computer operation. Simulated data are fed into the computer's input/output circuits by the program. This routine checks all relays and switch positions to the computer and the output and input modules of the computer. Furthermore, since most of the data used by the fire control system is in analog form, the program must test the encoders (analog-to-digital) and decoders (digital-to-analog) of the computer.

MARGINAL CHECKING

Marginal checking is a preventive-maintenance technique that is used to detect the decrease in reliability of circuit parts due to aging. Aging circuit parts almost invariably change in value, current-handling capabilities, or voltage limitations. Generally, the changes brought about by aging are gradual, and you will not notice any variation in the normal operation of the equipment. For maximum equipment reliability, parts that are beginning to deteriorate

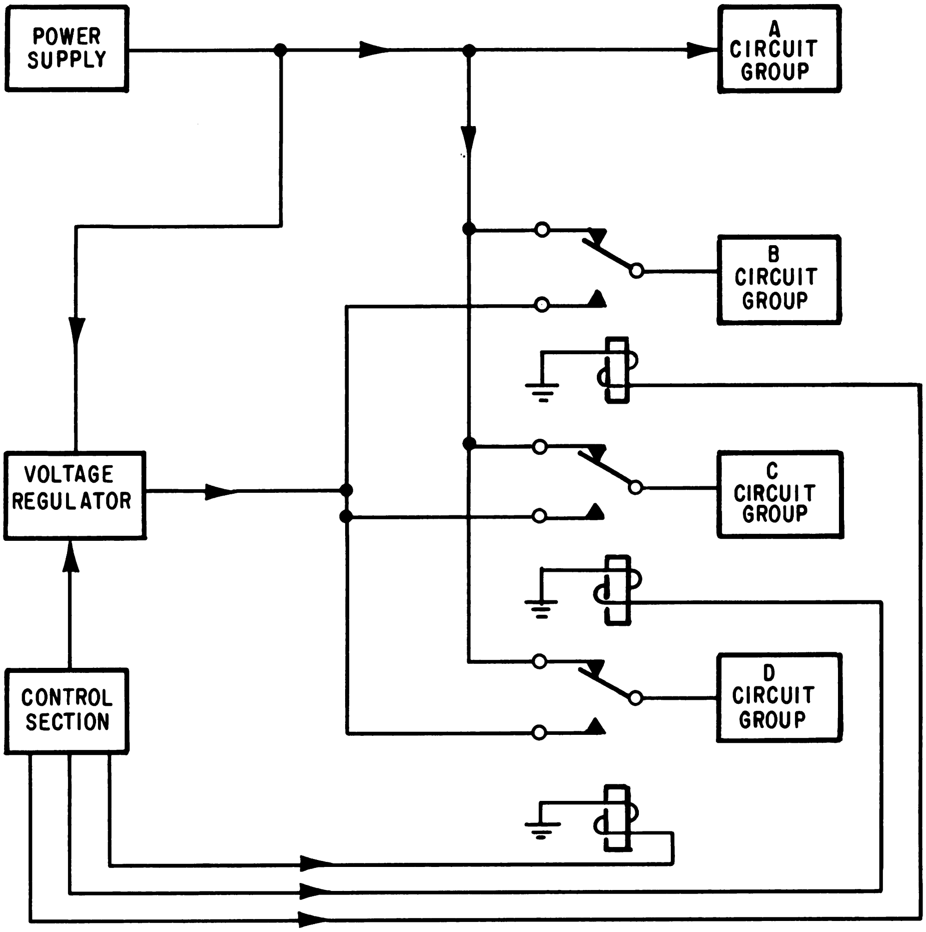

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Figure 7-15.—Marginal checking units, simplified block diagram.

must be detected and replaced before a failure occurs.

Marginal checking is usually controlled by a maintenance program. The program directs the computer to perform the normal computer operations of addition or subtraction, while the program varies certain circuit parameters about their normal values. In this way, the computer is made to perform normal functions under adverse operating conditions.

To accomplish marginal checking, certain operating conditions are changed from their normal values. Since circuit part values normally change with age, the variations that can be introduced before a failure occurs become fewer as the parts age. The amount of variation, from the normal value, that can be introduced before equipment failure occurs is called the margin of reliability of the circuit, or group of circuits, being tested. If the margin is regularly checked, and its gradual decrease noted, circuit failure can be anticipated. There are three methods of changing operating conditions for marginal checking:

1. Variation of d.c. supply voltages
2. Variation of circuit values
3. Variation of electron-tube filament voltages

Marginal Checking Units

Marginal checking units for variable supply voltage applications include a voltage-regulator unit, relays to connect the test voltage to circuits, and control circuits necessary to initiate marginal checking. When high currents must be furnished by the regulator, an amplidyne may be used to provide a variable d.c. supply voltage. This device provides a well-regulated output voltage that can be accurately controlled over a wide positive-to-negative range.

A simplified block diagram of marginal checking units is shown in figure 7-15. The relays, which are controlled by maintenance programs, can connect any one of three circuit groups to the marginal checking voltage regulator. Circuit group A represents circuits that cannot be effectively tested by this method; therefore, it is not connected to a relay in the marginal checking circuit.

CHAPTER 8

DIRECTORS AND ANTENNAS

INTRODUCTION

The director and antenna (fig. 8-1) act as the eyes of the fire control system, establishing the line of sight (los) to a target by optical equipment or by radar equipment. With the director mounted as high as practical aboard ship, the los is raised high above the gun position. The target can then be seen clearly despite gun blast and sea spray, and can be observed at greater distances than is possible from the gun.

Some directors are large and heavy and are manned by equipment operators (fig. 8-2), while others are small and light and consist of only a pedestal or support for a radar antenna (fig. 8-3). In either case, they act as the eyes of the fire control system.

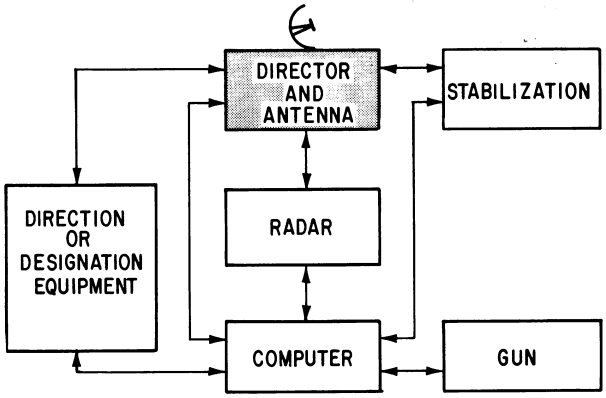

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Figure 8-1.—Director and antenna act as the eyes of the fire control system.

In this chapter, we will discuss the function of a director, how it establishes target position and tracks a target, stabilization of the los, modes of operation, and power drives. Hence, this chapter will acquaint you with the theory of operation of directors and, in addition, it will provide you with the background knowledge necessary to understand the director and antenna power drives.

POSITION OF THE LINE OF SIGHT

The primary function of a director is to establish and maintain the los on target. Target position is measured by two angular quantities—director train (Bd) and director elevation (Ed). It is also measured by the linear quantity range (R). These quantities are shown in figure 8-4. From your studies of the fire control problem, discussed in chapter 5, you should recognize this as the spherical coordinate system, which is used by all directors. Bd is measured by moving the entire rotating structure of the director. The base ring upon which the director rotates is part of the ship's structure and is installed approximately parallel to the deck plane. Thus, Bd is measured with respect to the deck plane. The los is positioned in elevation by rotating the radar antenna or the optical equipment around the elevation axis in its mountings. Therefore, it is not necessary to move the entire director to change Ed. Since the director is mounted parallel to the deck plane, Ed is measured with respect to the deck plane. Range is measured in the slant plane to the target (fig. 8-4).

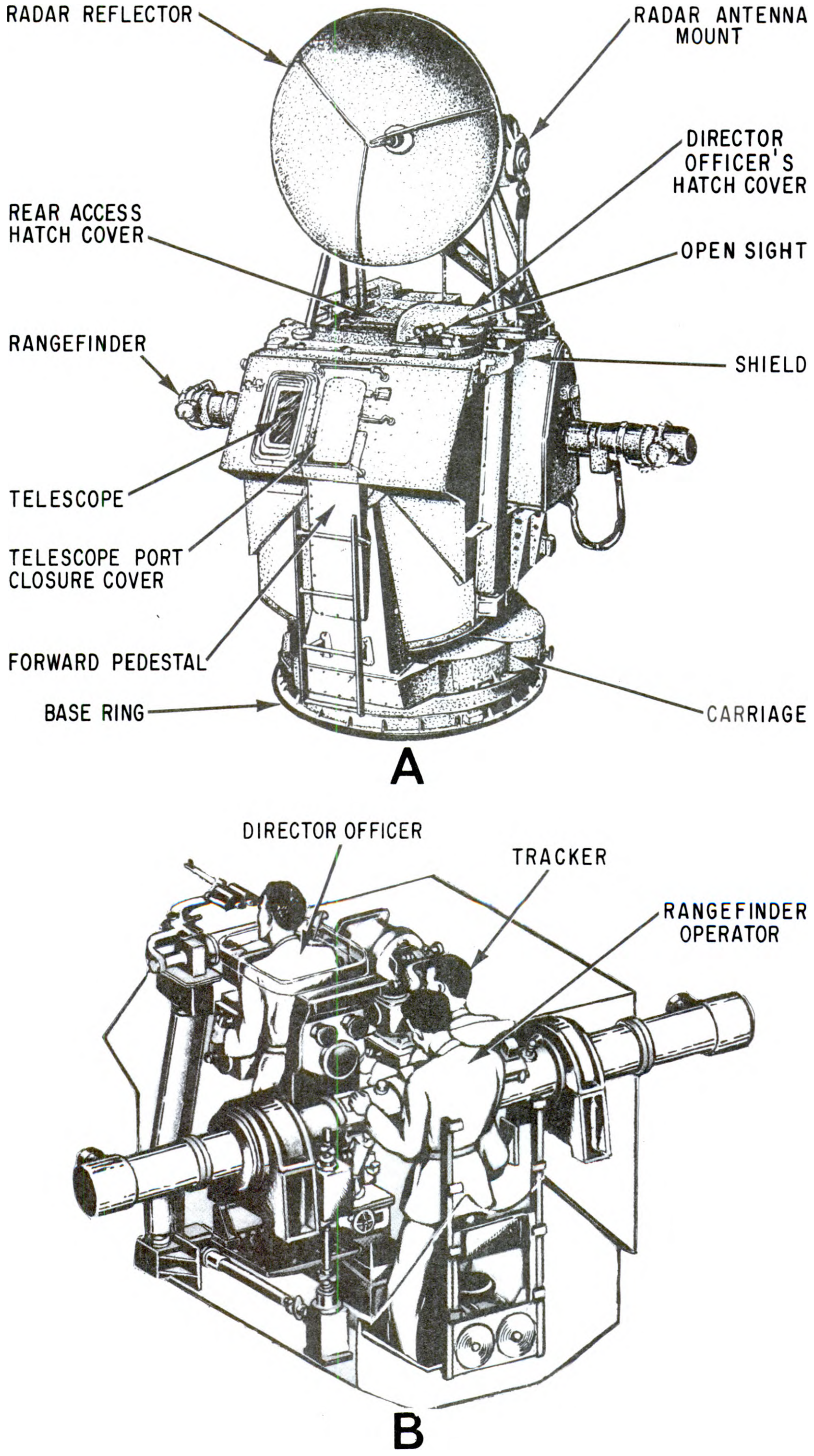

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Figure 8-2.—A. Gun director Mk 68, exterior view. B. Director crew stations, interior view.

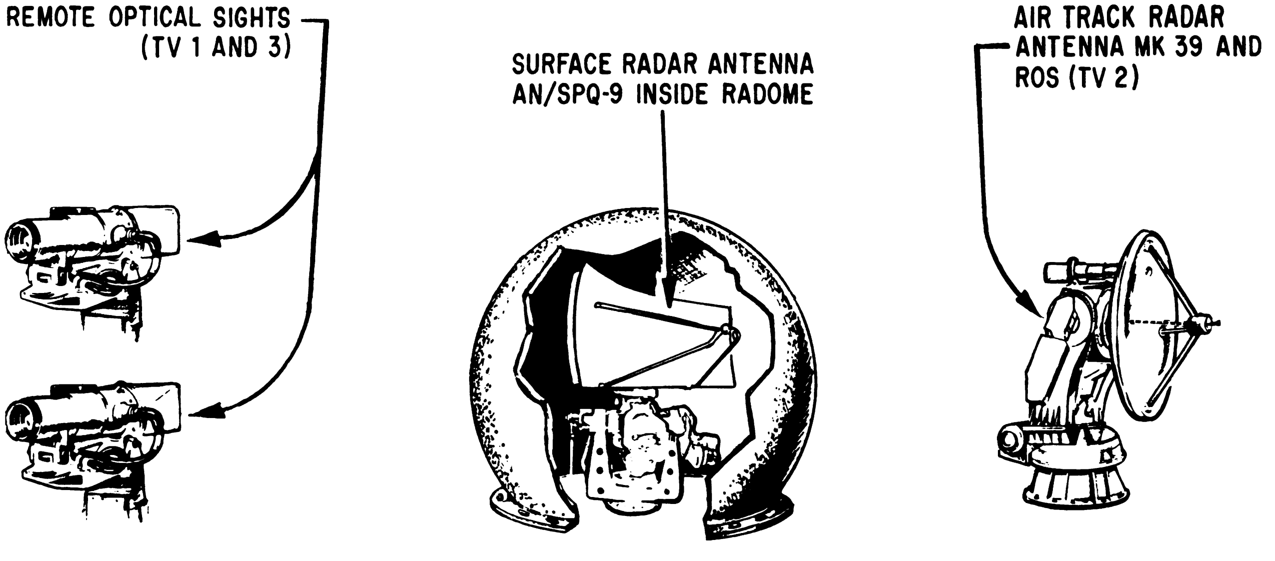

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Figure 8-3.—Above deck system components.

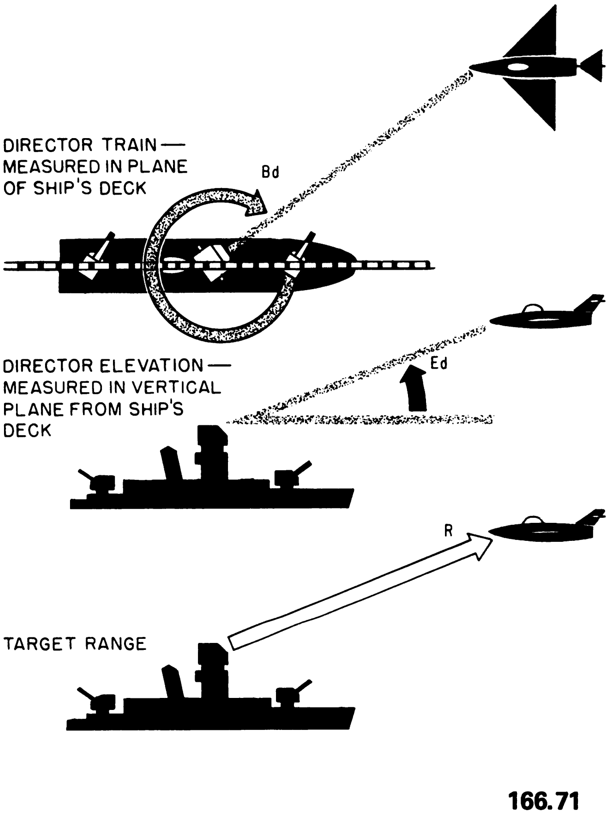

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Figure 8-4.—The primary function of the director.

The los is the connecting link between ownship and the target. The target is tracked by keeping the los on target. The director can automatically control its position accurately enough so that we can say that the target tracking line and the los are coincident.

STABILIZATION

We wish to establish and maintain the los to the point in space occupied by the target. This point is independent of ownship's motion, since its position in space does not change as the ship moves. But the origin of the los (the director) will move up and down, and from side to side as the deck of the ship tilts. Therefore, continuous corrections to compensate for ownship's roll and pitch are necessary to keep the los on target. This means that the values describing target position with respect to the deck plane are continuously changing.

How do roll and pitch affect the measurement of target position? With ownship on an even keel, the deck plane is in the horizontal plane, and the normal plane, which is perpendicular to the deck plane, is in the vertical plane, which is perpendicular to the horizontal plane. The los to a target is contained in a slant plane in the vertical and normal planes. When the deck is tilted, the normal plane is tilted out of the vertical plane. An unstabilized los will rotate with the normal plane, and the bearing and elevation describing target position will change values. But, if the los is stabilized so that it is maintained in the vertical plane, which is stationary with respect to ownship's roll and pitch, changes in the bearing and elevation will be greatly reduced.

The director tilts with the deck as ownship rolls and pitches. If there were no corrections for ownship's roll and pitch, the target would appear to move with respect to a telescope's crosswire, as shown in figure 8-5. If the ship were tilted in the vertical plane containing the los, the target would appear to move above or below the horizontal crosswire (fig. 8-5A). The angle by which the crosswire is displaced vertically from the target is the LEVEL ANGLE.

If the ship were tilted in the vertical plane across the los (fig. 8-5B), the crosswires would remain on target, but they would rotate around the los. The angle, measured in the vertical plane ACROSS the los, made by the horizontal crosswire and the horizontal, is CROSSLEVEL.

With both level and crosslevel present, you would see the target as shown in figure 8-5C. Notice that the telescope crosswires are displaced vertically as a result of level, and rotated around the los as a result of crosslevel.

The first step in stabilizing the los is to establish a horizontal reference plane that is not affected by the tilt of the deck. As you know from your studies of gyroscopes in chapter 4, the stable element establishes the horizontal reference plane aboard ship and its gimbal system references deck tilt to the los. The outputs of the stable element are level, crosslevel, and level plus a function of crosslevel. The level angle can be used directly, since it coincides with the director's elevation axis (fig. 8-6). Level is assumed to be positive when the deck is tilted down toward the target, and is

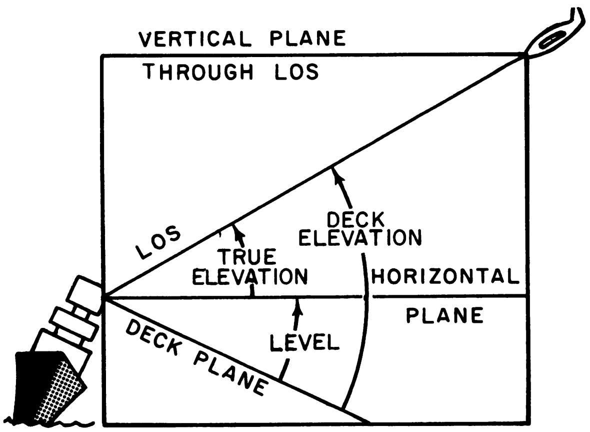

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Figure 8-6.—Elevation angles in the vertical plane.

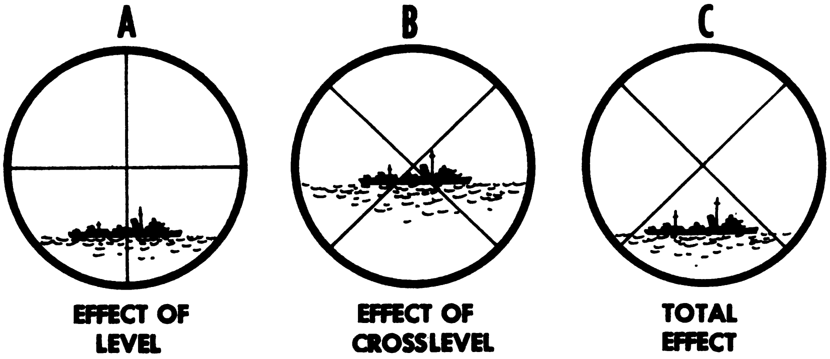

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Figure 8-5.—Target as seen through a telescope.

added to director elevation above the deck plane to obtain target elevation above the horizontal plane. Conversely, a negative level angle with the deck tilted up toward the target is subtracted from director elevation. Level and director elevation are in the vertical plane, which is not affected by deck tilt. The director will be elevated in the vertical plane if its elevation axis is in the horizontal plane. Crosslevel is used to keep the director's elevation axis in the horizontal plane.

You can see in figure 8-5C that deck tilt across the los causes the director elevation axis to move out of the horizontal plane. The tilt of the elevation axis around the los is NOT coincident with the director's axes of motion. Therefore, the tilt cannot be compensated for directly by moving the director in train or elevation. We must tilt or rotate the optical system, the radar antenna, or the whole director, to keep the elevation axis in the horizontal plane.

Figure 8-7 shows a director telescope housing, as well as a schematic view of how it works. The housing is secured to the director and will tilt with it. The elevation input drives the ring gear, which rolls freely around the telescope and acts as an idle gear. The other spur gear, meshed with the ring gear, drives the wormwheel, which in turn drives the sector gear and the elevation prism. The crosslevel input is fed to the telescope through a wormwheel and sector gear and rotates within its housing. Crosslevel will tilt the telescope in the opposite direction to deck tilt and, in so doing, will keep the telescope crosswires aligned with the horizontal/vertical planes.

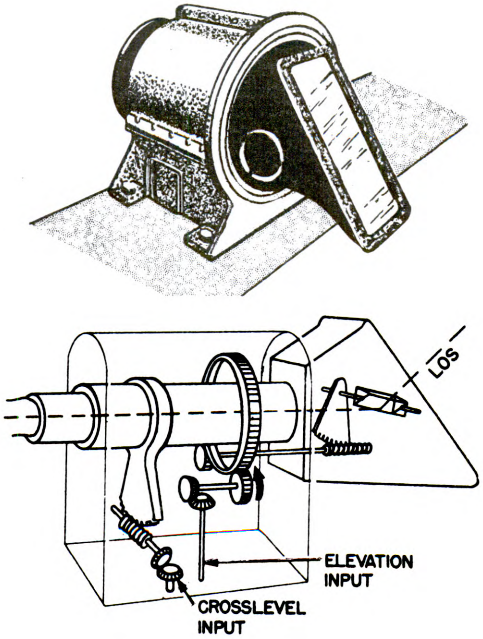

Figure 8-7.—Director telescope.

MODES OF OPERATION

The units of a fire control system are integrated (work together). Therefore, the director, the radar, and the computer are in the same mode of operation. The mode of operation is shifted by system switching and relays in the control circuits of the units. Many of the control circuits are interconnected between units and are interdependent. For example, when an automatic tracking radar locks on target, it automatically shifts to track and causes the director and computer to shift to the track mode.

The names given to the modes are descriptive of the director's operation.

STANDBY OR AIR READY

In the standby or air ready mode, the director is ready for instantaneous operation. The power drives are energized, with the exception of B+ voltages to the power drive amplifiers and the high voltages to the drive motors. The power drives' brakes at the director are applied.

DESIGNATION OR ACQUISITION

Upon proper system switching, the director is shifted to the designation mode. In the designation mode, the director power drives are fully energized and the brakes are off. The designation signal, a position signal, controls the power drives. The normal source of designation is from the Weapon Designation Equipment (WDE). Fire control systems are also interconnected to provide intersystem designation.

The director accepts the designation signals and drives to the designated position. Once synchronized, the director will follow any change in the signals. Since position signals are used in designation, separate channels or circuits are provided to adapt the power drives to accept this type of signal. Director power drives are usually not self-synchronous except in the designation mode. In track mode, a director follows rate signals from a position it has established.

The designation signal to the director may be modified by a search signal. The search signal moves the los about the designated position. In some fire control systems, the computer initiates the search signals, while in other systems it is initiated in the director. In either case, the director power drives follow the designation signal plus any modifying search offset.

TRACK

When the director acquires the target, the system is put into the track mode. This is done by the radar locking on the target, or the director operators closing a key or switch. The position circuitry used in designation is decoupled from the director power drive amplifiers, and a track channel is substituted.

Tracking commences with the los on target. Tracking rates are obtained from measurements of target displacement from the los, which develops during track. In optical control, the director operators are the error detectors. The trainer, for example, observes the target through the telescope, and turns the handwheels to keep the los on target. Movement of the handwheels is used by the computer to correct the tracking rate fed to the synchro differential (fig. 8-8).

Automatic Tracking

Automatic tracking radars produce voltages which are proportional to target displacement from the los. Hence, the radar is the error detector. Elevation and train tracking systems are identical; therefore, only train is discussed here. Figure 8-8 is a functional block diagram of the train system. The radar antenna is in conical scan (tracking mode). The rf echo return is amplitude and phase modulated. When the target is off the boresight axis of the antenna, the magnitude of the modulation indicates the amount of target displacement, while the phase of the modulation indicates the direction of the displacement. The radar's error detector produces control voltages proportional to the modulation, and therefore to target displacement. The control voltage is amplified and used to drive the servomotor. The servomotor is mechanically coupled to the synchro differential (DG) which feeds the signal to the control transformer (CT) in the director drive. The director train motor moves the director (and antenna) to eliminate the error.

Computer Aided Tracking

Computers which generate increments of relative motion of the los transmit this information to the director as an aid to keep the los on target. In figure 8-8, increments of computed bearing from the computer are an input to the synchro differential (DG). The output of the differential is the algebraic sum of the computer signal and the radar's target displacement signal. The output signal is the input to the synchro control transformer in the director power drive. If the radar momentarily loses the target, the director will continue to move at the last computed rate.

Tracking is a closed loop. The director accepts designation and slews to the designated position. The radar acquires and then locks on the target. The director power drives, working in conjunction with the computer, stable element, and radar, keep the los on target.

LOCAL OR TEST

Provisions are incorporated in the director power drives to break the closed loop and operate the director locally. The local control signals originate in the director or at the radar

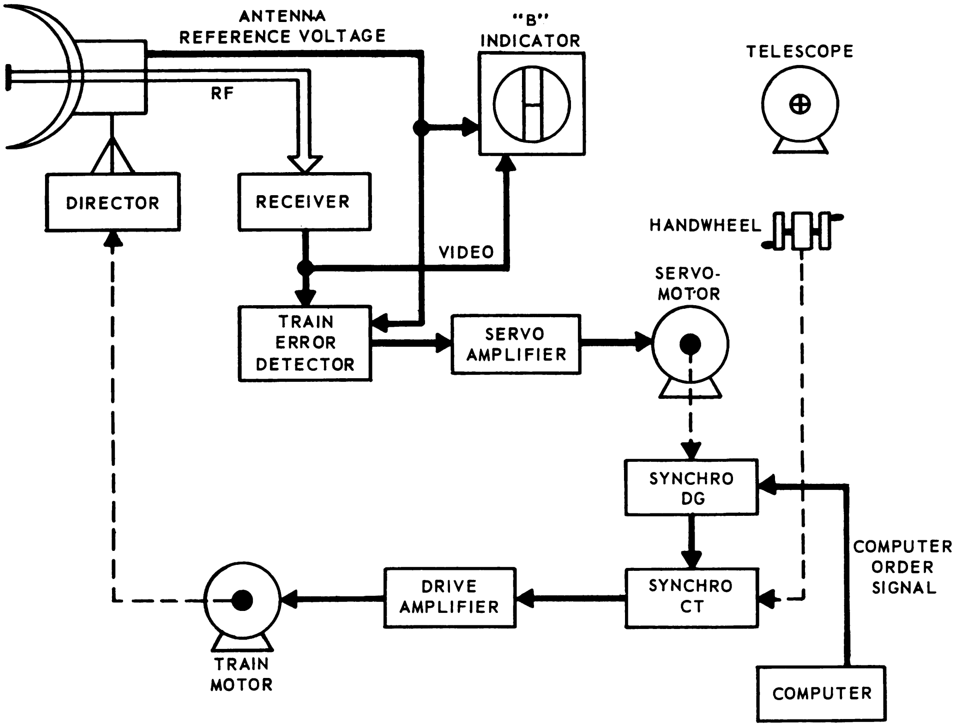

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Figure 8-8.—Block diagram of train tracking system.

console. Going back to figure 8-8, you can see that the handwheels can be used to furnish a local signal in this system. In the local mode of operation, relays in the power drive decouple the automatic signal from the drive and a local voltage is substituted. Not shown in the illustration, but included in the power drive, is a slew sight for rapid acceleration of the director.

When the slew sight is deflected from its neutral position, it varies the current to the field windings of a slew motor. Hence, the amount of deflection of the slew sight controls the speed of the slew motor which is geared to the CT.

In some power drive systems, local control signals are originated at the radar console. In some of these systems, synchros located in the console are substituted by relay action for the computer's signals. The position channel used in the designation mode is used in the local mode. The radar operator turns a handcrank connected to the local control synchros and drives the director to the desired position.

Another method of originating local control signals at the radar console is to use a reference voltage proportional to the desired velocity signal. Radar operators have a joystick or handcrank with which they can vary the magnitude and the phase or polarity of the reference voltage. This voltage is substituted for the normal tracking signals.

Local control furnishes a means of local acquisition of targets, using the fire control radar scopes. The director power drives can be tested independently of the radar's automatic tracking system and the computer.

DIRECTOR AND ANTENNA POWER DRIVES

Director and antenna power drives are servosystems, most of them similar to those that were discussed in chapter 3. In this chapter, we are going to discuss another type of servosystem called the amplidyne drive. The reason for discussing the amplidyne drive in this chapter is because the only place you will find it used in a fire control system is driving directors and antennas. This topic is important to you, because as a fire control technician, you will frequently be expected to test, adjust, and repair these power drives.

AMPLIDYNE DRIVE

An amplidyne drive is a servosystem that uses both a conventional electronic amplifier and a rotary amplifier (amplidyne generator) to supply controlled power to position heavy loads. Figure 8-9 shows a typical amplidyne drive. Notice the similarity between this diagram and

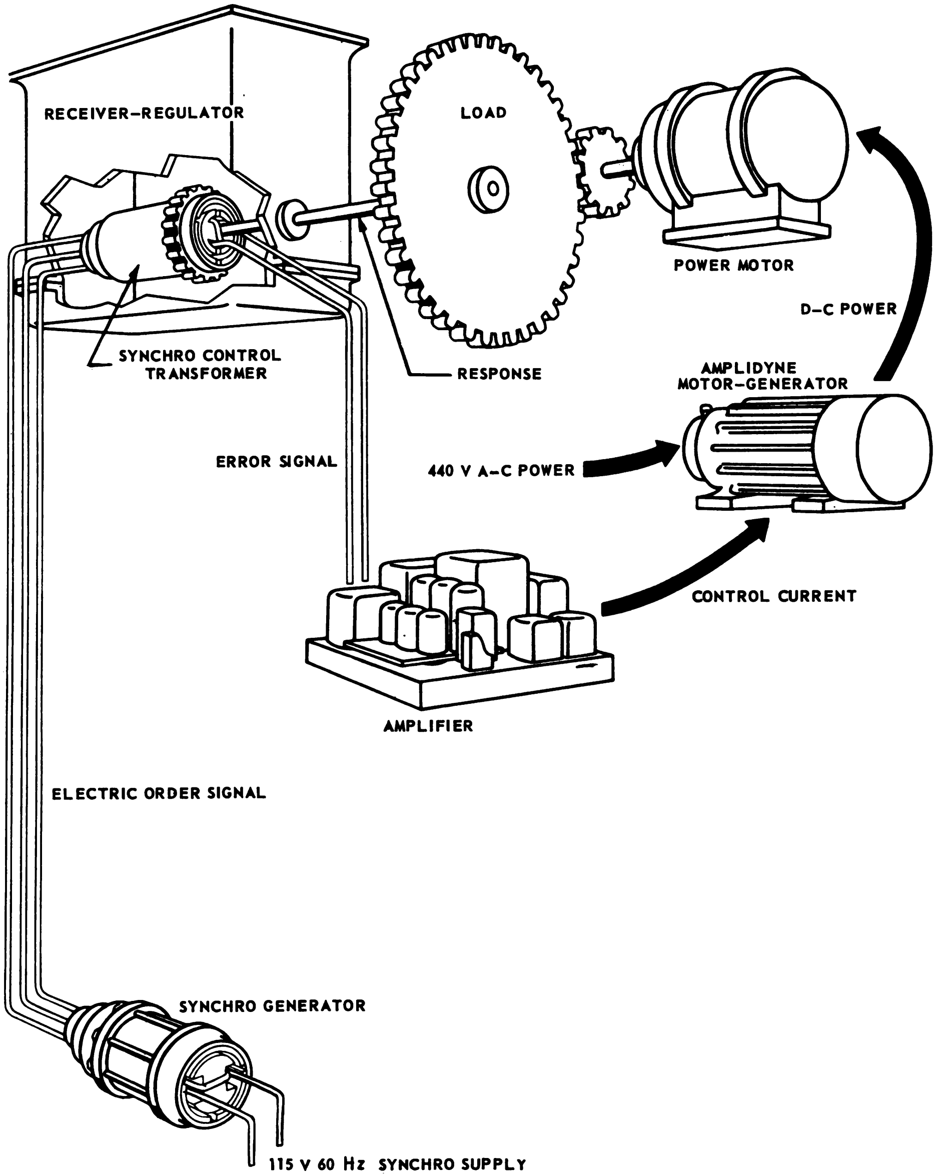

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Figure 8-9.—Basic amplidyne drive.

that of a basic servo in figure 3-2. We can apply the nomenclature used in chapter 3 to the units shown in figure 8-9. For example, the synchro generator is the order device, the synchro control transformer is the error detector, and so on.

Amplifier

The amplifier in the diagram rectifies and amplifies the a.c. error signal. The output stage of the amplifier is arranged in push-pull configuration. Thus, the output of the amplifier is two opposing d.c. currents. This output furnishes the control currents for the amplidyne generator. The amplidyne generator is the rotary amplifier of the power drive. This is the instrument which amplifies a low-powered signal into one strong enough to drive the director. If the principles of d.c. generators (particularly armature reaction) and amplidyne generators are hazy in your mind, review the *NEETS* modules on a.c. and d.c. motors and generators.

Amplidyne Generator

Figure 8-10 is a simplified schematic diagram of the amplidyne generator, the drive motors, and their associated circuits. A conventional a.c. induction motor drives the generator. The generator is rotated in one direction, and at a constant speed. The generator excitation is supplied by the control windings F1-F2 and F3-F4. The control windings are energized by the opposing d.c. currents from the amplifier. These windings create a magnetic field which is the resultant of both currents. With a zero error signal to the amplifier, the d.c. outputs are equal and opposite. Therefore they cancel, and no control field is present in the generator. When there is an error signal to the amplifier, one of the d.c. currents will increase while the other will decrease a like amount, and a resultant magnetic control field will be present in the generator.

The control field causes a relatively large current in the armature winding that is shorted by the brushes. This armature current creates a strong quadrature field. The unshorted armature windings cut the quadrature field causing a large current in the windings. This current is delivered to the load by the load brushes.

The magnitude of the generator output is determined by the strength of the control field. The polarity of the generator output is determined by the polarity of the control field. Thus, both the magnitude and polarity of the generator output are determined by the d.c. current input from the amplifier. Later in the chapter we will see how the amplifier

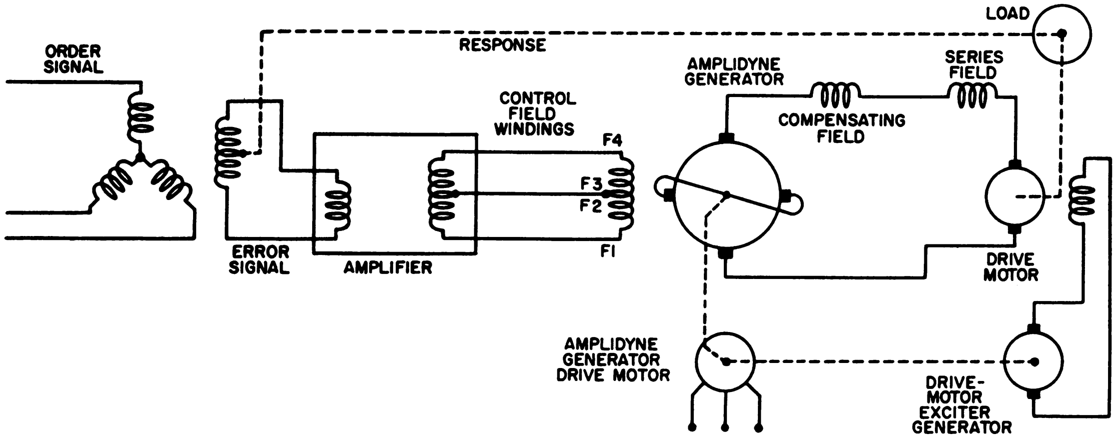

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Figure 8-10.—Simplified diagram of the amplidyne generator and associated circuits.

determines, from the a.c. error signal, which d.c. output should be the stronger.

The compensating winding in the generator is used to compensate for armature reaction. Armature reaction is caused by the magnetic field created by the current delivered to the load. This current passes through the compensating winding, which creates a magnetic field. The compensating winding magnetic field and the load current magnetic field cancel each other.

This is fundamentally how an amplidyne generator works, although other refinements are necessary to achieve the fast stable operation that is needed in driving a fire control director.

Drive Motor

The drive motor is a d.c. motor of conventional design, having an armature circuit and a magnetic field. In a permanent-magnet d.c. motor the magnetic field is supplied by permanent magnets built into the stator. In the separately excited type, the magnetic field is provided by a stator winding which receives a steady d.c. current from a source separate from the motor. In both types, the armature current comes directly from the amplidyne generator.

The drive motor has a steady excitation field. Thus, the direction of rotation depends only on the direction of the current in the armature. The torque applied by the motor to the load depends on the volume of this current. Therefore, the motor's direction of rotation and torque depend on the output of the amplidyne generator.

Feedback Circuits

To keep the director's los on target, the power drives must be very sensitive to changing input signals. But, stable operation is definitely a requirement of the power drives. Feedback voltages are used to stabilize the operation of the power drives. The number of feedback voltages and their strength are determined by load characteristics and by the type of response required. These stabilizing voltages modify the effect of the power drive input error signal, but do not interfere with normal operation. Stabilization was covered in chapter 3 under servomechanisms.

There are three stabilizing voltages commonly used in amplidyne follow-up systems—speed, current, and jitter voltages. Figure 8-11 shows the source of these voltages in the train follow-up system.

SOURCE OF THE STABILIZING VOLTAGES.—The speed voltage is obtained from a d.c. tachometer generator, which is geared to the train drive. This makes the generator output proportional to the director's speed. The output polarity depends upon the direction of movement of the director. In the diagram, you can see that this voltage is dropped across potentiometer R18. This voltage opposes the error signal and thus governs, to some extent, the errors on speeding up and slowing down the director.

The current stabilizing voltage is obtained from the series field of the drive motor. The voltage across the series field is proportional to the current drawn by the drive motor. This voltage is most effective when the drive motor draws heavy current, for example at starts and reversals. This voltage is dropped across potentiometer R17.

To obtain the third stabilizing voltage, a special winding is built into the stator of the amplidyne generator (fig. 8-11). This winding is called the quadrature winding, and it is placed at a right angle to the control winding. In this position, the quadrature winding is cut by the quadrature field. Since this field is created by a d.c. current, it has a constant magnitude when a constant signal is applied to the generator. The flux lines of the quadrature field thread through the winding and do not induce a voltage. But when the strength of the quadrature field changes, a voltage is induced in the winding. This happens only when the load on the amplidyne changes. Thus, the voltage induced in the quadrature winding is proportional to the rate of load change and the frequency of the quadrature flux changes.

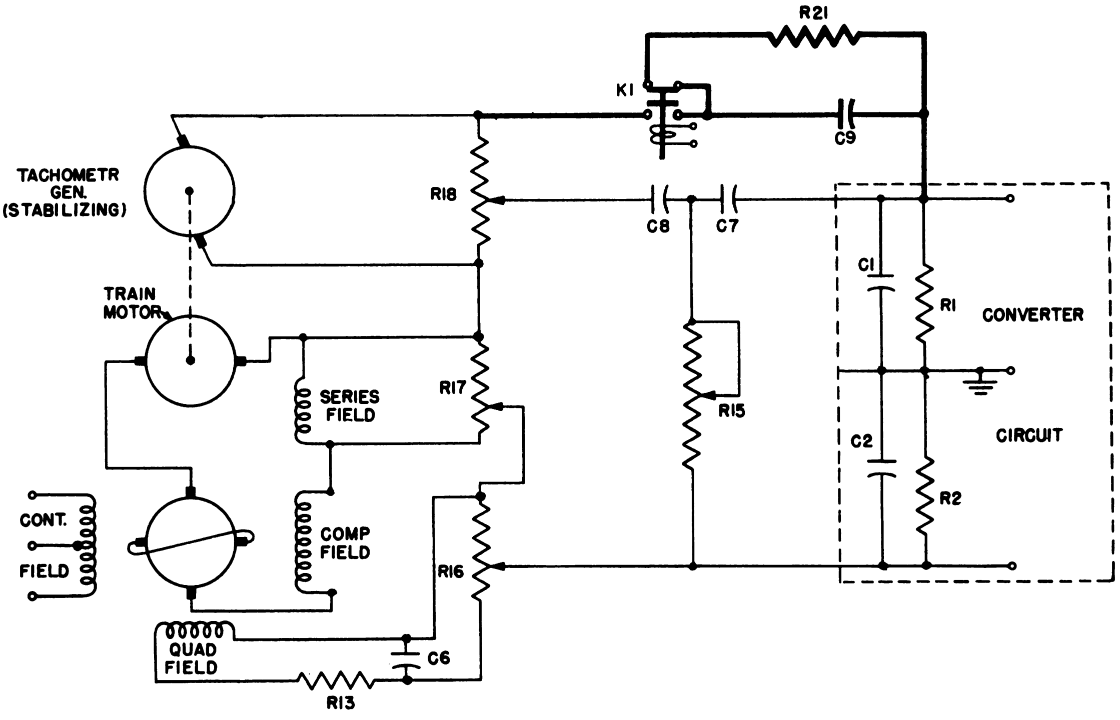

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Figure 8-11.—Train stabilizing circuit.

The rate of load change is greatest when the director is reversing fastest, during jitter. For this reason, the voltage in the quadrature winding is called the jitter stabilizing voltage. The jitter voltage is dropped across potentiometer R16.

Every follow-up system has one or more natural oscillating frequencies which depend on the weight of the load, designed speed of the system, and other characteristics. In the train amplidyne system, all three of the stabilizing voltages are needed to control hunting and jitter. In other systems, the characteristics are such that only one or two of the signals are necessary.

COMBINING THE STABILIZING VOLTAGE.—As explained, each stabilizing voltage is used to overcome a particular type of oscillation. Since each of these voltages is applied to an adjustable potentiometer, the percentage of each voltage in the remainder of the circuit can be controlled. Therefore, we can adjust the amount of each of these voltages to obtain the best operation of the director. The potentiometers are connected in series. Thus, their output voltage will be the algebraic sum of the three voltage percentages.

The stabilizing voltages are direct current. As long as the director is operating normally, and is moving at a constant speed, condensers C7 and C8 will effectively block the d.c. voltages (fig. 8-11). But when the director is oscillating, the polarity of the voltages is reversed on every swing, and they become low frequency a.c. voltages. The resulting alternating current can pass through the condensers. The condensers and their associated resistors will pass the frequencies found in oscillations, but will block the lower frequencies in the range of the roll and pitch of the ship. Hence, they constitute a high-pass filter. The result is that there is no appreciable current flow in resistors R1 and R2, except when the system is unstable.

The potentials developed across R1 and R2 are determined by the direction of director movement. The two potentials of opposite polarity are used to modify the error signal in the converter stage of the amplifier. The potentials are always in opposition to the error signal, and are thus a form of negative feedback.

Potentiometer R15 (fig. 8-11) is in parallel with resistors R1 and R2. R15 provides a path for bypassing a part of the stabilizing current to adjust its total effect on the amplifier.

TRAIN DRIVE

A director or antenna needs separate power drives for its movements in train, elevation, and crosslevel. Since all these power drives are basically the same, we will discuss only the train drive. If you understand this section, you should not have any difficulty understanding the technical manuals on amplidyne power drives of the fire control system to which you may be assigned.

Figure 8-12 shows a typical train circuit for an amplidyne power drive. It contains the train synchro circuit, the 36-speed control transformer (CT), which furnishes the error signal to the amplifier through the input transformer T1. The CT also supplies the same error signal to the synchronizing circuit (T6, V6, and K1). The amplifier has two stages. The first stage (tubes V1 and V2) is a converter demodulator. The second stage (tubes V3 and V4) is a push-pull power stage. The d.c. voltages for this stage are supplied by the full-wave rectifier circuit (T2, V5, filter circuit T5 and C5, and the voltage divider circuit R10, R11, and R12). The output of the amplifier is fed to the control field of the amplidyne generator. The output of the generator is applied to the train motor. Stabilizing voltages are supplied to the amplifier by the stabilizing tach, the series field in the drive motor, and the generator quadrature field. These voltages are combined, and the combined voltage is an input to the amplifier via the various potentiometers, resistors, and condensers.

Train Amplifier

The amplifier has two stages—the converter stage and the output stage. The converter stage produces two direct currents, one of which is greater when the error signal calls for the director to move in one direction, the other when the director should move in the opposite direction. When the error signal is zero, the currents are equal. To provide these two currents, the converter stage rectifies and amplifies the error signal. The direct currents are used to control the output stage, which provides further amplification. The outputs of the amplifier control the amplidyne generator.

CONVERTER STAGE.—The converter stage is shown in figure 8-13. This stage compares both the phase and the magnitude of the a.c. error signal from the control transformer with that of a reference voltage taken from the synchro supply. The error signal is either in phase or 180° out of phase with the reference voltage. The magnitude of the error signal will vary, whereas the value of the reference voltage is constant. The outputs of the converter stage are two d.c. potentials. This circuit is similar to the triode demodulator you studied in the *NEETS* module on modulation principles.

The plates of V1 and V2 (fig. 8-13) are connected to opposite ends of the secondary windings of transformer T3. The tube's circuits will therefore act as full-wave rectifiers. Since the grids are connected to opposite ends of transformer T1, the circuit will compare the phase relationship between the a.c. voltage inputs. The instantaneous polarities shown in the figure are for an in-phase right-train error signal. With these polarities, tube V1 will conduct heavily. First one section and then the other section of the tube will have its plate and grid positive at the same time. The plate circuit for V1 is through a part of the winding of T3, down through R3, and back to the cathode through the common cathode resistor R20 and part of potentiometer R14. Notice that the current through R3 is always in one direction.

Meanwhile, back at V2, the plate that is positive will have a negative grid. The tube will

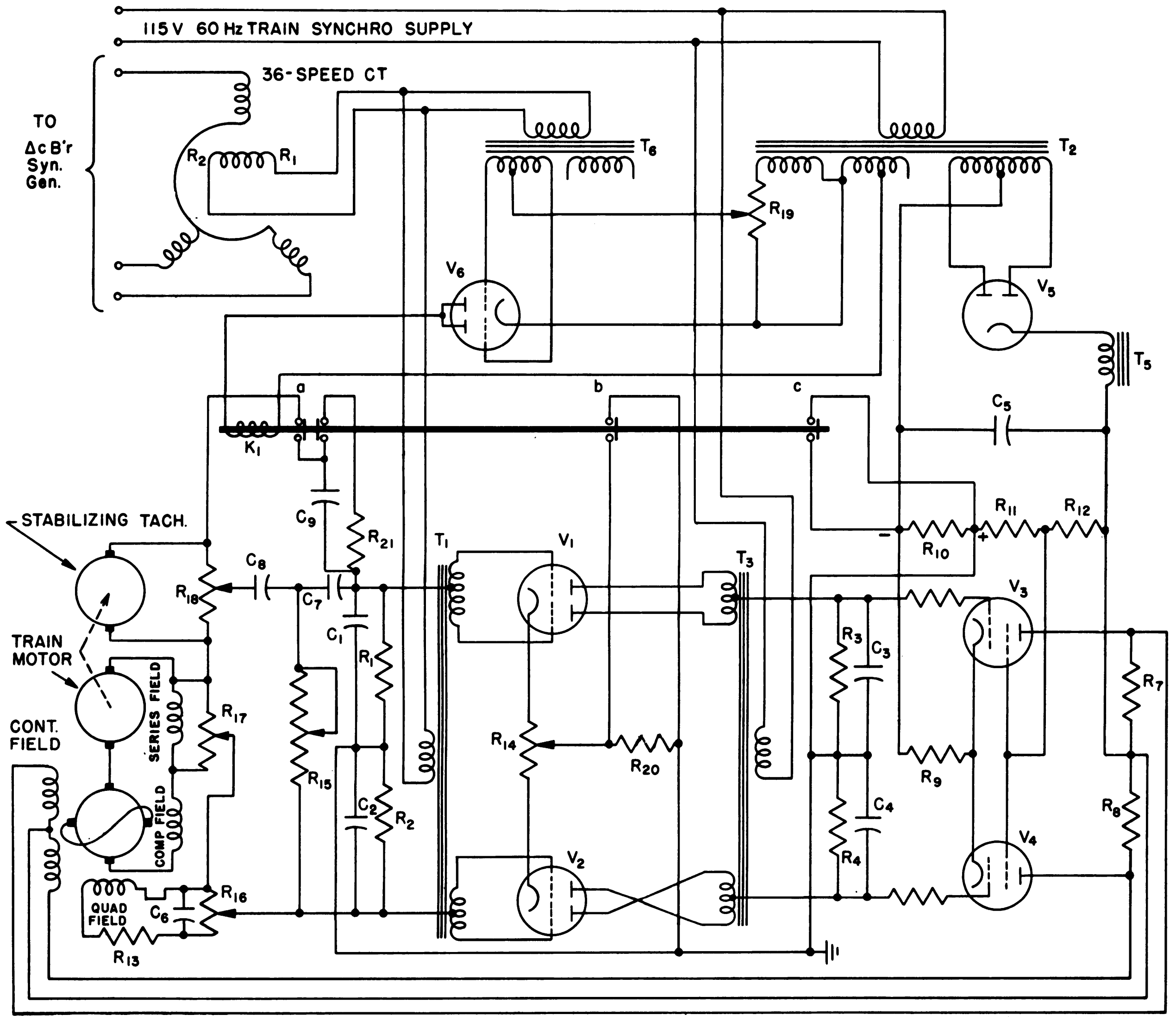

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Figure 8-12.—Train circuit.

conduct a slight amount under these conditions. Its plate circuit is through a part of T3, up through R4, and back to the cathode through R20 and a portion of potentiometer R14. The current through R4 will always be in one direction.

When the error signal is out of phase with the reference voltage, V2 will conduct heavily, and V1 slightly. The outputs of the converter circuit are the d.c. potentials taken from the top of R3 and the bottom of R4. These potentials are applied to the grids of the second stage of the amplifier. With a zero error signal, the two potentials are equal. When an error signal is introduced into the converter, these potentials swing in opposite directions. Condensers C3 and C4 smooth out the voltages received from the first stage.

Resistors R1 and R2 and condensers C1 and C2 are part of the stabilizing voltage input circuit to the amplifier.

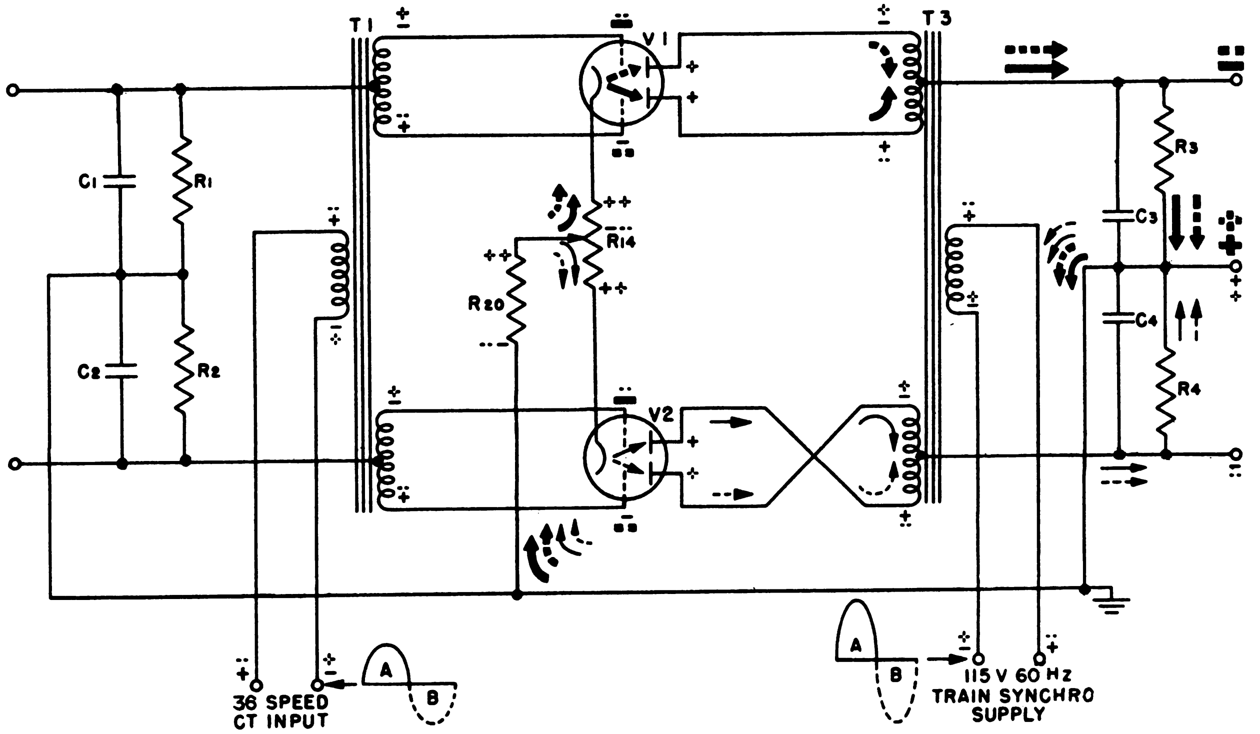

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Figure 8-13.—Train converter circuit.

BALANCE ADJUSTMENT.—As explained earlier, the two control-field currents in the amplidyne generator should be equal when the error signal is zero. To provide equal outputs from the amplifier for a zero error signal, a circuit balance adjustment potentiometer R14 is connected in the cathode circuits of tubes V1 and V2 (fig. 8-13).

The potentiometer, R14, and the common cathode resistor, R20, provide self-bias for both V1 and V2. One end of the potentiometer controls the bias on tube V1, and the other end the bias on tube V2. By moving the potentiometer finger, the bias on one tube will be increased and the bias on the other decreased. Thus, the output of the amplifier to one control field is increased and that to the other is decreased. The adjustment has been properly made when equal control currents are obtained with a zero error signal.

OUTPUT STAGE.—The output stage consists of tubes V3 and V4 and their related circuits (fig. 8-14). The tubes receive a negative bias voltage from the d.c. outputs of the converter stage. When these potentials are equal, the outputs of the tubes are equal. The grid of V3 receives a potential from the top of R3. This is a negative potential produced by the current flow down across R3. Thus an increase in this current will increase the negative potential applied to the grid of V3. This, naturally, will reduce the current flow through V3. A decrease in current flow across R3 will have an opposite effect on the current flow through V3.

The grid of V4 receives its bias from the bottom end of R4. The negative potential at the bottom on R4 has the same effect on V4 as that of R3 and V3.

An error signal present in the converter stage will result in the two d.c. potentials swinging in opposite directions. This means that tubes V3 and V4 will receive opposite-going signals. Thus, one tube will have an increase in conduction,

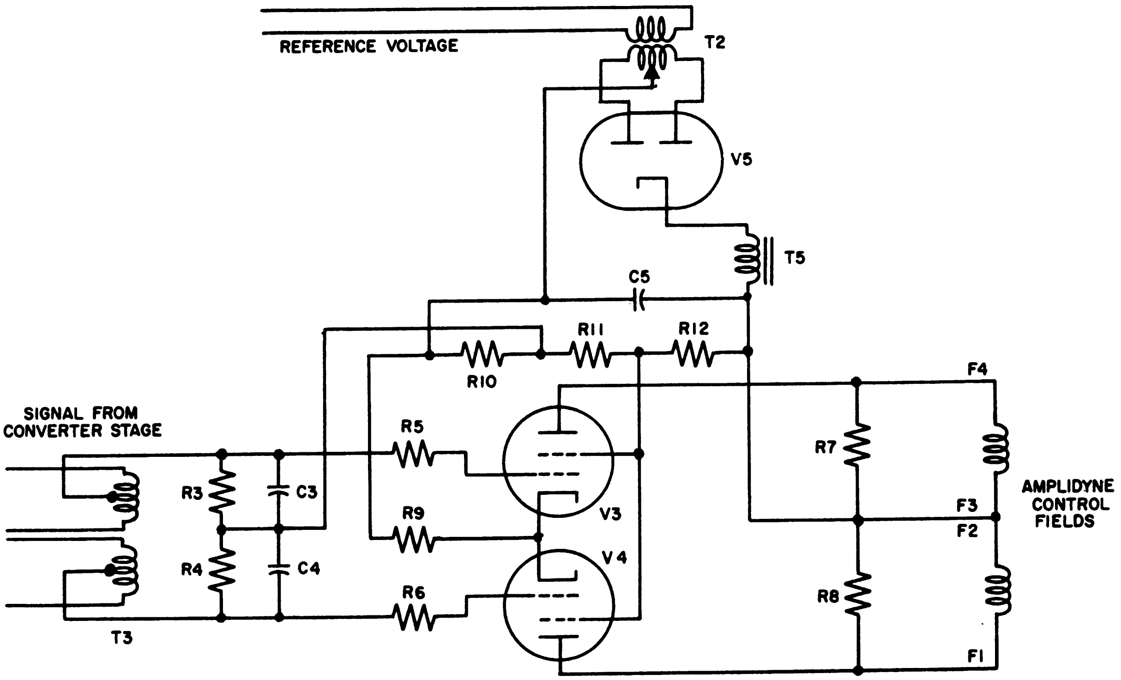

Figure 8-14.—Output stage of the amplifier.

while the other tube will have a decrease in conduction. The plates of the tubes are connected to the control windings in the amplidyne generator. The control fields will no longer cancel, and the amplidyne will have an output.

Tube V5 is a full-wave rectifier of conventional design which furnishes plate supply for the output stage. Resistors R10, R11, R12 form a voltage divider network. Notice that R10 is between the cathodes and control grids of the tubes, and furnishes positive bias voltage to the tubes.

The stabilization circuits for this drive were used as an example when we discussed feedback circuits for amplidyne power drives and will not be discussed here.

Train Synchronizing Circuit

The purpose of the synchronizing circuit is to prevent overspeeding of the drive when large error signals are present. This is done by reducing the sensitivity of the amplifier. The director is originally positioned by the target designation system or by the director trainer. When the director goes into automatic, the 36-speed error signal keeps the director on target. Since the signal is received from a 36-speed transmitter, synchronism can be obtained at 36 positions, each 10° apart. Thirty-five will be false positions and only one will be the true synchronizing point. If a large error signal is allowed to drive the equipment at an excessive speed and there is a radical change of target speed or direction, the inertia of the moving heavy equipment could become so great as to drive past synchronism in excess of 5°, causing it to synchronize at a false point.

The principle parts of the synchronizing system are tube V6 and relay K1, shown in figure 8-12. V6 rectifies and amplifies the error signal from the control transformer. The output of V6 is used to energize relay K1.

Relay K1 will be energized and picked up for all error signals in excess of approximately 50 minutes of arc. When the relay is energized, it performs the following functions.

1. The contacts at point "c" short out resistor R10. This resistor normally supplies positive bias to the grids of tubes V3 and V4. Thus, the gain of this stage is reduced.
2. The contacts at point "b" short out resistor R20, which supplies negative bias to tubes V1 and V2. This action increases the output of these tubes. Since V1 and V2 furnish negative bias to V3 and V4, the amplifier output is further reduced.
3. The contacts at point "a" connect the whole stabilizing voltage of potentiometer R16 through capacitor C9 to the amplifier. The increased stabilizing voltage dampens the increased tendency toward instability which comes with high speed.

Since we want maximum sensitivity to small errors, relay K1 does not operate below approximately 50 minutes of error. The exact value depends upon the setting of potentiometer R19.

This means that the single 36-speed system will produce correct synchronism if overspeed is prevented. That is why the synchronizing circuit is designed to apply relay K1.

There is no need for this circuit when the error signal is less than 50 minutes. Therefore, the K1 relay does not operate below this amount of error. Also, eliminating the relay's circuits during small errors will increase sensitivity. This increases the accuracy for small errors.

The synchronizing relay circuit is shown in figure 8-15. The figure will be explained for a zero error, or for an error signal of less than 50 minutes. Let us trace out the plate and grid circuits for alteration B of the supply by following the broken arrows.

K1 is connected in series with the plate of V6. Whatever current flows through V6 also flows through K1. The plates of V6 are positive with respect to the cathode, and the grids of V6 are biased near cutoff by the large voltage across the bottom secondary of T2. V6 passes only a

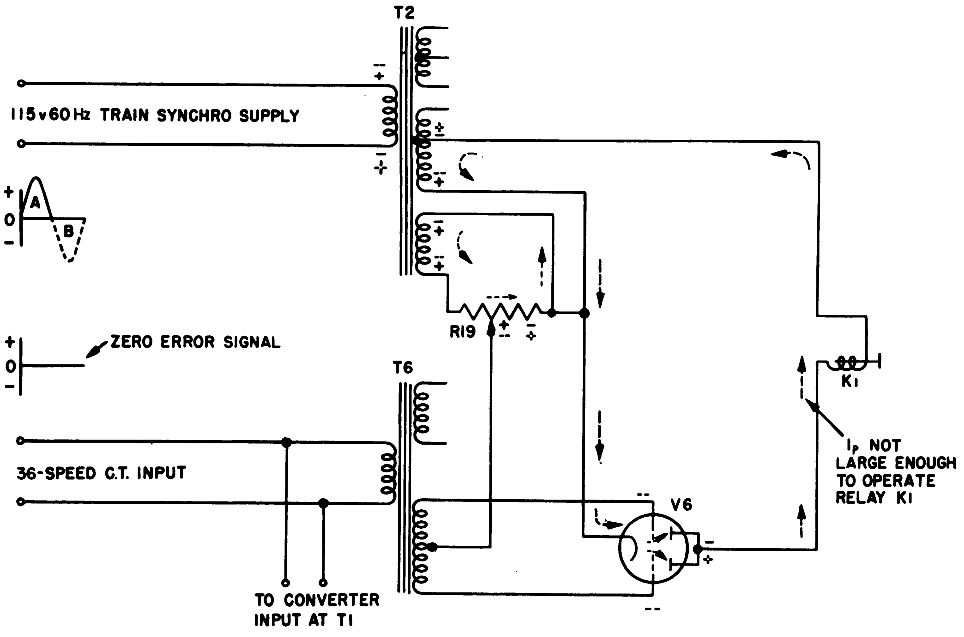

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Figure 8-15.—Synchronizing circuit, zero signal.

small current through K1, insufficient to energize it.

SUMMARY

Directors and antennas act as the eyes of a fire control system, establishing the line of sight to a target. Directors and antennas are mounted as high as practical aboard ship to be able to see greater distances. They are stabilized in level and crosslevel to maintain the line of sight at a fixed point in space. The modes of operation of a typical director and the entire gun fire control system were discussed. Some director and antenna systems are driven by amplidyne power drives. As a fire control technician, you will be expected to test, adjust, and repair these power drives. A working knowledge of these power drives is essential.

CHAPTER 9

FIRE CONTROL RADAR

Radar is a term derived from Radio Detection and Ranging. The term "radar" signifies a method in which radio waves are employed to detect the presence and location of objects in space.

Target detection is accomplished by transmitting a beam of radio-frequency energy over the area to be searched or scanned. When the energy strikes a reflecting surface, a small portion of the energy is reflected or reradiated toward the original radiating source. A sensitive receiver located near the transmitter detects the echo pulse and, therefore, the presence of the target.

To determine the target's position in space, it is necessary to find its three positional coordinates (range, bearing angle, and elevation angle) within a required frame of reference.

The tactical use of a radar determines the requirements which it must meet. These, in turn, determine its circuits and components and its operating characteristics. Fire control radar is one of the classes of shipboard Navy radars. The other classes are search radar and special radar. Basically, radar is a data-sensing element. Since the purpose of a fire control system is to destroy a selected target, the radar's job (fig. 9-1) is to obtain as much accurate data about the target as possible. The more data the system has, the more likely it is to score a hit on the target.

In this chapter, the principles and fundamental elements that make a fire control radar system perform are discussed.

BASIC PRINCIPLES OF RADAR

Radar, in brief, works on the echo principle. The radar radiates waves of radio-frequency (rf) energy. The waves, for all practical purposes, can be considered to travel in a straight line until all the energy is expended. If the waves strike an object, some of the rf energy is reflected. This is called an echo. The echo returns to the radar by a reciprocal path and indicates the presence of an object in the wave's path. To be really useful, the radar must be able to determine the exact location of the object.

RADAR RANGING

Radar ranging is based on the fact that the rf energy travels at a constant velocity and in a straight line. The wave's velocity is independent of its energy level. Thus, a weak echo travels at the same speed as a strong transmitted wave. Radar determines range by measuring the time it takes the energy to travel from the radar antenna to the target and back again to the radar. Because the waves must travel to the target and back again before the echo can be detected, target range is half the total distance traveled.

The velocity of rf waves in space is the same as that of light—162,000 nautical miles (186,000 land miles) per second. Obviously, 162,000 miles is too large a figure for our use. Therefore, the unit used to measure time is the microsecond (a millionth of a second). The rf energy travels approximately 1 nautical mile in about 6.18 microseconds. Neither ownship nor target motion changes the rf energy's velocity.

The rf energy is reflected by the target instantaneously and no time is lost at the target. There is a delay in the radar receiver, called the transit time of the receiver, but this is a constant characteristic time delay for which compensation is made.

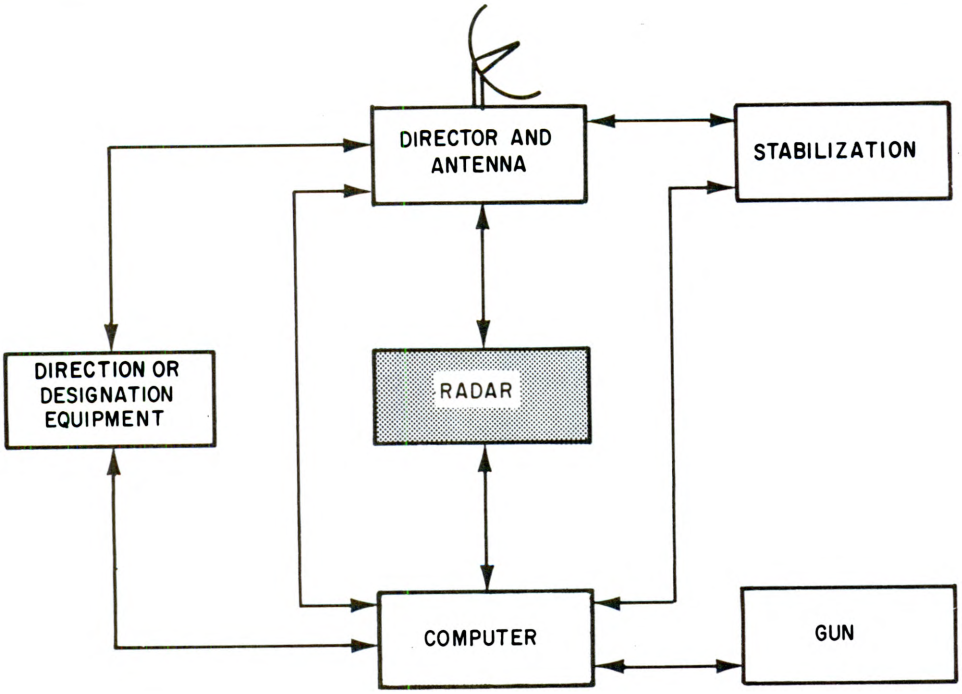

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Figure 9-1.—Radar is used to detect the presence and location of objects in space.

The formula for radar range is as follows:

$$\text{Radar range (in nautical miles)} = \frac{\text{Microseconds between transmission and echo return}}{12.36\ \mu s}$$

The denominator, 12.36 microseconds, is the time it takes the rf energy to travel 2 nautical miles; remember, the reflected energy must make a round trip between ownship and the target. It would be impossible for a person to count off the microseconds, but it can be done with ease electronically. An oscilloscope can be used to graphically display the passage of microseconds. Since range is a linear function of time, the scale associated with the oscilloscope's sweep, which represents time, can be graduated in units of range (miles or yards).

To use the range formula, the radar must be able to pinpoint exactly when the energy reflected by a target left the radar. One method of determining the exact time the reflected energy left the radar is to pulsemodulate the radar transmitter. A short signal pulse triggers the radar transmitter and causes it to start radiating. The radar transmits for a short time, and then shuts down. The instant the transmitter starts to radiate is zero reference time. The trigger pulse also starts the radar receiver's timing system. While the transmitter is shut down and the timer is running, the radar's receiver "looks" for a return echo from that burst of rf energy. After a time, depending on the pulse-repetition rate (prr) of the radar, the process is repeated.

TARGET LOCATION

A surface target can be located by its range and bearing. To define the location of an air target, range, bearing, and elevation (or target height) are needed. Fire control radars compare the strength of the echos returned by a target to determine bearing and elevation. To understand the principles involved, we must first discuss the form of the transmitted energy in space.

The radar antenna forms the rf energy into a narrow beam. The center axis of the beam corresponds to the boresight axis of the antenna (fig. 9-2). The beam is divided into quadrants by a vertical axis and a horizontal axis. The beam's axes are mutually perpendicular and intersect at the boresight axis of the antenna.

The amount of rf energy or power density is greatest along the beam's centerline. The beam's power density decreases by an amount proportional to the displacement from the beam's centerline axis. Therefore, when a target is not in the center of the beam, it returns a weaker echo than if it is exactly on the beam's centerline axis. Generally, the radar beam is swept over the area surrounding the target in such a way that the returning echos vary in amplitude, which is dependent on the position of the target with respect to the beam's centerline axis.

A target at a given range, located on the vertical axis but in the upper fringes of the beam, returns a weak echo. As the beam is elevated, the strength of the echo increases as the boresight axis approaches the target's position. When the beam's boresight axis intersects the target, a maximum echo is returned. If the beam continued to elevate, the echo's strength would be reduced in proportion to the distance of the target below the boresight axis. The same principle is applied to determine target bearing, except that the amplitude of the echo varies in respect to target displacement along the horizontal beam axis.

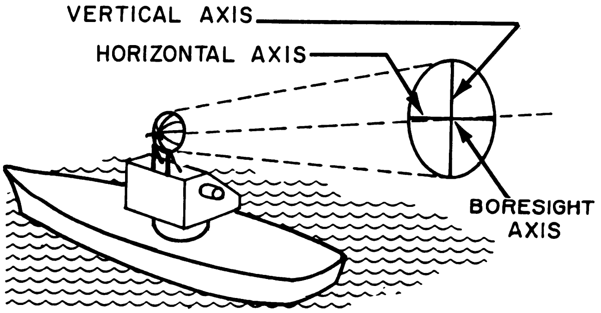

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Figure 9-2.—Beam pattern.

The radar must provide the fire control system with continuous bearing and elevation information. Obviously, if the radar antenna is continually moving to locate the target in the beam, the information furnished the system is bound to be very rough. Instead, the beam is scanned systematically about the antenna's boresight axis. The principle of echo strength versus target position in the beam is still used. Beam scanning is covered later in this chapter.

CLASSES OF FIRE CONTROL RADARS

Fire control radars may be classified by their general use, by their method of modulation, by their frequency or wavelength, by their method of scanning, or more frequently, by their method of transmission. Of course, there are other methods of classification, but the ones listed are used most frequently.

When fire control radars are classified according to use or the weapon they direct, they are divided into three general categories: (1) gun fire control radars, (2) missile fire control radars, and (3) gun and missile fire control radars (some fire control radars can direct the ship's guns and missile launchers simultaneously).

Fire control radars can be divided by their method of transmission into three general classes: (1) pulse-modulated, (2) continuous-wave and (3) pulse-doppler radars. Pulse-modulated radars transmit pulses of rf energy. The radar's pulse repetition rate (prr) determines the usable range of the radar. The time between the transmission of the rf energy and the echo return is measured electronically and displayed graphically by a cathode-ray tube (crt). A pulsed radar, with its precise measurement of transit time, can measure range accurately.

Continuous-wave (cw) radar, as its name implies, radiates rf energy continuously. The frequency of the rf energy in the echo is changed by a moving target. This change in frequency is called a doppler shift. The doppler shift is used for target detection and to indicate the target's range rate. It is possible, by the use of filter circuits, to reject all targets except those traveling at or near a selected velocity. Since the radar transmits continuously, it can provide target information without interruption. It is, therefore, an ideal radar to illuminate a target for a semiactive homing missile. The radar has a transmitting system aboard ship and a receiving system in the missile. But, because the radar transmits continuously, it has no pulse reference by which it can measure transit time and range directly.

Pulse-doppler radars combine the best features of both the cw and the pulsed radars. The name tells us the radar is pulse modulated and that the doppler shift in the returned rf energy is used. The prr is much higher than that of the conventional pulsed radar and the pulse length is longer. A pulse-doppler radar, therefore, transmits a greater percentage of the time than a conventional pulsed radar. A radar that transmits more than 10 percent of the time has some of the characteristics of continuous transmission and is considered to be a cw radar. But, since it is pulsed, a pulse-doppler radar can measure range by using transit time. The doppler shift can be used to obtain measure of the target's range rate and as a means to operate the radar receiver with a narrow bandwidth. The narrow bandwidth enables the radar to reject unwanted targets and noise.

FUNCTION OF RADAR IN FIRE CONTROL SYSTEMS

A radar set is designed for the particular fire control system in which it is to be used. The radar's capability must be compatible with its functions in that system. Fire control radars have many uses and are very versatile. They are used to detect and track surface and air targets, guide a missile to a target, illuminate a target for a missile's homing system, operate with a radar beacon, transmit and receive coded identification and command signals, and spot (correct) the fall of shot for surface fire.

Target Position Determination

The first job performed by the radar is determining target position with respect to ownship. The radar is normally assisted in acquiring the target by signals from the designation system. However, to decrease target acquisition time, the fire control radar beam is scanned over the area surrounding the designated target position. Once the target is acquired, the radar's scan pattern is reduced to concentrate on the target.

The fire control solution is based on the radar's measurement of the line of sight to the target. In the design of fire control radars, emphasis is placed on extreme accuracy in range and position measurements. To meet this need, super-high transmitted frequencies are used and pulse systems are caused to operate at a high prr. The radar antenna has a parabolic reflector that forms the radiations into narrow "pencil" beams.

Target Tracking Systems

Once the target is centered in the beam, the radar tracks the target to provide continuous line-of-sight information. Tracking is usually accomplished automatically. The tracking systems operate on the same principle as the servosystems that you have already studied. In a servosystem, the error signal is the input to a servoamplifier. The output of the amplifier is the input to a servomotor which drives the system until the error has been eliminated.

When the radar is not "on target" in range, there is an error signal from the range error-detecting circuits. This error signal is used to provide a signal voltage to the range servo that drives the ranging circuits, to eliminate the error signal. Likewise, when the radar antenna is not trained directly at the target, there is an error signal output from the train error-detecting circuits. This error signal is used to develop a voltage input for the train servoloop, to drive the antenna mount until the error has been eliminated. The elevation tracking system keeps the antenna on the target in elevation. When the target is moving, tracking is a continuous process.

Spotting

Radar provides a means of spotting surface fire, which is independent of conditions of visibility. Shell splashes appear on a radar scope as fluctuating echos, which last for several seconds. The radar operator can count off or estimate the distance in range and bearing between the target and the splashes and correct the next salvo to hit.

Radar Beacon Operation

Radar beacons are used to supplement the natural targets of the radar. Moreover, each installation has its own code and, therefore, is an improvement over the natural target. Beacons operate only when a signal with the proper frequency and code is received. The radar transmitter and beacon receiver are tuned to the same frequency. The beacon starts to transmit when it receives an rf signal from the radar. The beacon transmits back to the radar receiver. Thus, the beacon transmitter and radar receiver must be tuned to the same frequency. This frequency, however, does not have to be the same as the radar transmitter's and beacon receiver's. The frequencies selected depend on the application. A beacon is used in shore bombardment as a fixed target ashore, serving as a reference point. Some guided missiles contain beacons for the transmission of data between the missile and the fire control radar aboard ship.

Missile Guidance

Fire control radar is the source of guidance for guided missiles. The missile is like a puppet on the radar's electromagnetic string, dancing to the commands of the radar. The radar, and missile combination operates like an automatic tracking radar, with the error-detecting circuits and the servocontrol system in the missile. The position of the guidance radar antenna is controlled by the fire control system aboard ship. The guidance radar either follows a target tracking radar directly or is programmed so that its radar beam closes with the target in some prescribed manner.

FUNCTIONAL SECTIONS OF A FIRE CONTROL RADAR

The basic components of a fire control radar (fig. 9-3) can be divided into functional sections. This does not mean that all the components are located in the same cabinet or little black box. It does mean that all these components serve to produce one end function. They may, however, be located in different drawers or cabinets throughout the radar system.

The most common radar in the gun fire control field is the pulsed radar. Therefore, this discussion deals mainly with this type of radar. While radar systems vary greatly in design (depending on the jobs that they are to perform), they all have many similar functional sections. This will become evident to you as you complete this section of the chapter.

TIMING SYSTEM

The timing system establishes a time reference for the radar; that is, it sets up the order in which the units of the radar operate. The pulses produced by the timing system trigger the modulator, the receiver, the indicator, and the ranging and automatic tracking systems.

A radar determines range by measuring the elapsed time between the transmission of the rf pulse and the reception of the echo. Therefore, time in the various functional systems must be correlated. Following is an example of how the timing system can measure time electronically and relate time to range.

Assume that an oscillator circuit produces a sine-wave voltage with a frequency of 163.88 kilohertz (kHz). If the oscillator were highly stable, the output wave would vary linearly with time (the sine wave would take a definite amount of time to complete a cycle and there

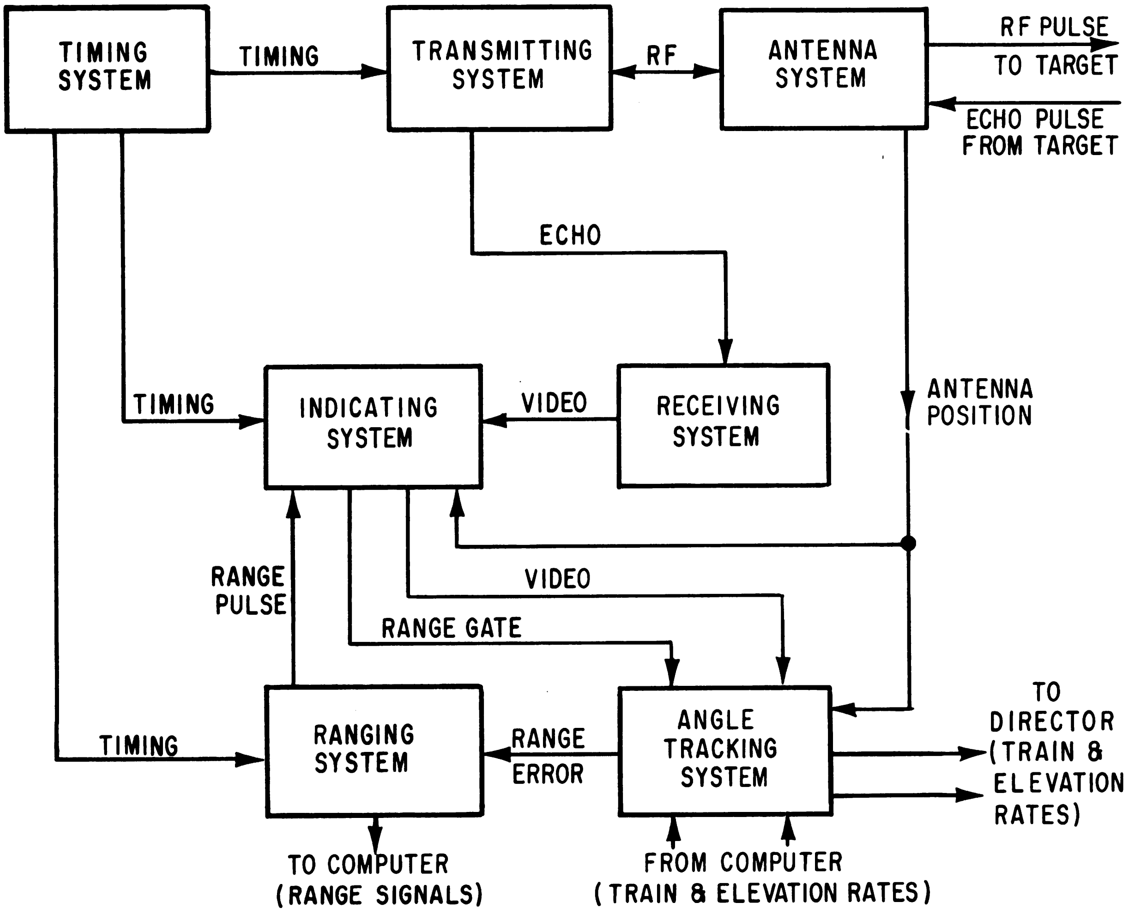

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Figure 9-3.—Functional block diagram of a pulse radar system.

would be a fixed period of time between the positive peaks of the wave). It takes 6.1 microseconds to complete a cycle at this frequency. This is equal to the time it takes a radar pulse to travel to a target 1,000 yards away and return. Therefore, one cycle of the oscillator's output is equal, with respect to range, to 1,000 yards. Shaping circuits distort the sine wave into spikes occurring at 6.1-microsecond intervals. The spikes are used as reference marks for the radar's timing system.

The reference marks are basic timing triggers essential to the operation of the entire radar. But the marks have not been related to a zero reference time. They are like the minute hand of a clock. The passage of time can be measured with the minute hand but to be completely useful, the hour hand is necessary to establish a reference point from which to start. The zero reference time in a radar is the instant of radiation which is determined by the radar's pulse repetition rate (prr). Thus, the reference marks must be correlated with the prr for timing the operation of the units of the radar.

A second oscillator, which we will call the master oscillator, produces an output whose frequency corresponds to the prr of the radar. The output of the master oscillator, when properly shaped, is the main timing pulse that determines the time of the radar's transmission.

If the radar's prr were 1,250 hertz, a main timing pulse would occur every 800 microseconds. The frequency of the master oscillator's output must be stable in order to obtain accurate and constant results. But, the master oscillator is adjustable so that the radar's prr may be changed.

In some installations, a single master oscillator is used to time several radars. This is done to reduce the mutual interference between units of equipment, which operates on nearly identical carrier frequencies, and to coordinate the operation of radars, which must work in conjunction with each other. Most fire control radars can operate on either an internal or an external source of the main timing pulse.

The main timing pulse (also called the modulator pulse) is the radar's reference point from which time is measured. Once the radar has started to operate, the time relationship between the reference marks and the main timing pulse remains constant. Thus, the two sets of pulses are referred to as fixed references in the radar's timing system. To show how the two sets of reference pulses can be electronically correlated to control the timing of the radar's units, two circuits will be used—a coincidence amplifier and a blocking oscillator. As stated before, it is assumed that you have studied the *NEETS* modules on amplifiers and oscillators.

A coincidence amplifier, composed of a tube and associated circuits, requires the simultaneous application of two input pulses before an output pulse can occur. When only one of the inputs is present, there is no output. In other words, the tube is biased so that both inputs are needed to cause it to conduct, and the tube conducts only so long as both are present.

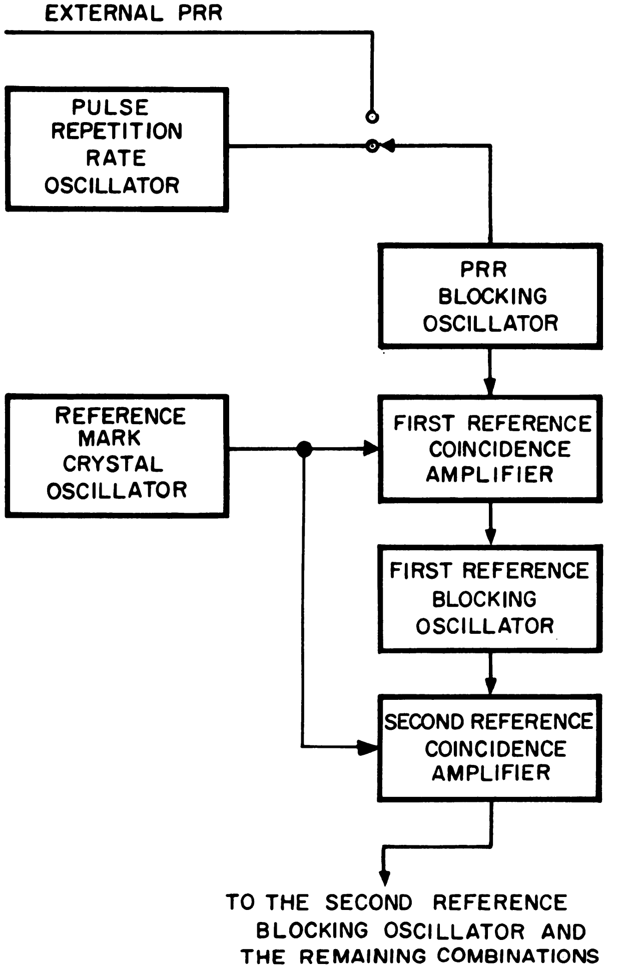
The coincidence amplifier can be used to correlate the two sets of timing pulses in a radar's synchronizer. A circuit (blocking oscillator) that depends upon the output of a coincidence amplifier to start its operation receives a signal pulse only when a reference mark and a master timing pulse are present in the amplifier.

There are two types of blocking oscillators: the triggered and the free-running types. We are interested in the triggered type. The blocking oscillator is a generating circuit. It is used to generate gating pulses with a definite duration, that recur at a specific frequency. The blocking oscillators and their associated circuits in the radar generate an 8-microsecond pulse when the oscillator is triggered by a timing pulse.

Now apply this information to a timing system. Since the radar measures range as a linear function of time, the units of the radar must vary linearly with time. Many of the units do not have this linear feature throughout their operational limits. For example, some radar indicators need a short interval in which to start their trace and become linear. Hence, it is necessary for the timing system to produce triggers that are separated by the time the units need to begin linear operation. But zero range must be coincident in time with the rf energy leaving the antenna. The modulator trigger to the transmitter is delayed a sufficient amount of time so that all the units are in their linear portion of operation and are aligned to the zero range when the rf energy leaves the antenna.

Figure 9-4 shows a simplified block diagram of the timing system. As shown, the prr pulse can originate externally or internally from the PRR oscillator. The prr pulse is fed into a blocking oscillator whose output is an 8-microsecond positive pulse. This pulse is applied to the first coincidence amplifier. The other input to the amplifier is the 6.1-microsecond reference mark from the crystal oscillator. The coincidence amplifier conducts only when both inputs are present. Since the prr blocking oscillator pulse is 8 microseconds long, at least one of the reference marks occurs while it is present.

In the first coincidence amplifier, a relationship has been established between the time the radar is to transmit and the reference marks which are used to measure time and range in the radar. The output of the coincidence amplifier is fed into the first reference blocking oscillator whose output is an 8-microsecond pulse. This pulse is applied to the second coincidence amplifier. The other input to the


EXTERNAL PRR
PULSE REPETITION RATE OSCILLATOR
PRR BLOCKING OSCILLATOR
REFERENCE MARK CRYSTAL OSCILLATOR
FIRST REFERENCE COINCIDENCE AMPLIFIER
FIRST REFERENCE BLOCKING OSCILLATOR
SECOND REFERENCE COINCIDENCE AMPLIFIER
TO THE SECOND REFERENCE BLOCKING OSCILLATOR AND THE REMAINING COMBINATIONS

12.313

Figure 9-4.—Simplified block diagram of a synchronizer system.

second coincidence amplifier is the reference marks. When both inputs are present, the amplifier conducts. This conduction is exactly 6.1-microseconds after that of the first coincidence amplifier. Blocking oscillators and coincidence amplifiers form combinations that provide delays in multiples of 6.1 microseconds. Radars that require longer delays have more of the combinations in series.

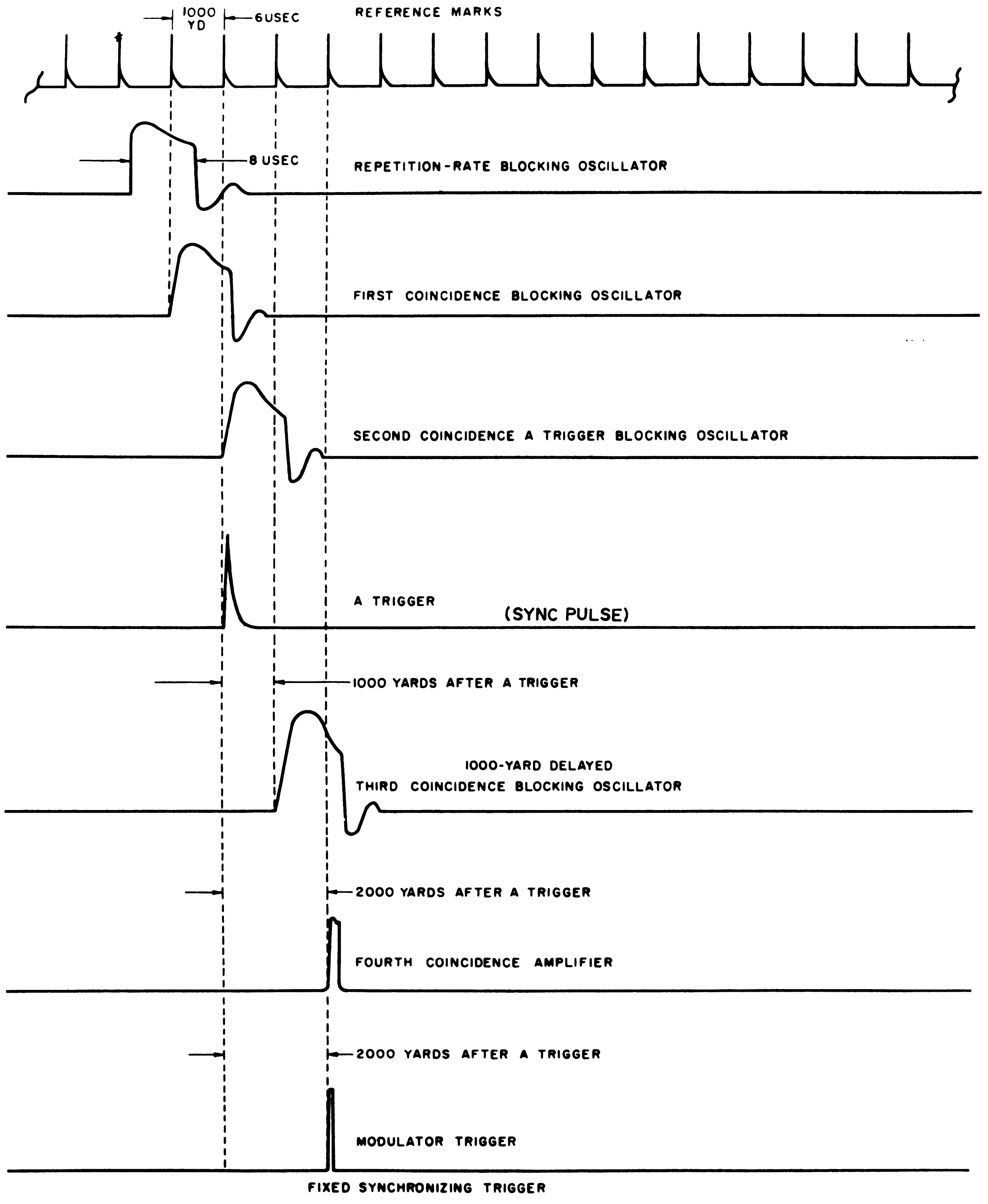
Figure 9-5 is a timing chart that shows the sequence in which the triggers are developed. The reference marks and the prr gate are the initial timing control signals. Notice the 6.1-microsecond delay between the outputs of the blocking oscillators. The "A" trigger, also called the sync pulse, is an output of the timing system that is used to start the "A" sweeps in the indicators and the circuits in the receiving, ranging, and tracking systems. The functions of the "A" trigger are covered when we discuss the other functional sections of the radar.

The rf energy in the radar's transmitter is generated in response to the modulator trigger (mod trigger) output of the timing system. Notice that the mod trigger is developed 2,000 yards after the "A" trigger. This is the delay in this hypothetical radar. Each radar, however, has its own timing requirements. Notice that the range in yards is used interchangeably with time in microseconds.

TRANSMITTER

The transmitter (fig. 9-3) generates and delivers pulses of rf energy to the antenna system. The transmitted rf energy of a fire control radar is in the microwave frequency band. The transmitted frequency of the various gun fire control radars is somewhere between 1,550 MHz and 10,900 MHz. The symbol MHz stands for megahertz, and is equal to one million cycles per second. These radars use an rf oscillator to generate the microwave energy. In pulse-modulated radars, the rf oscillator is turned on and off by a section of the transmitter called a modulator. The modulator contains the circuits that generate and shape the high-power pulse that is applied to the rf oscillator. The modulator is triggered when it receives the appropriate signal from the timing system.

The pulse repetition rate (prr) or pulse repetition frequency (prf), as it is sometimes called in fire control radars, is between 1,000 and 3,500 hertz. This means the modulator must produce this many pulses per second for the rf oscillator. The pulse duration is usually less than one-half microsecond and has an amplitude between 10,000 and 30,000 volts. When the transmitter is operating, the modulator must continue to supply a constant amplitude pulse, or the transmitted frequency may vary by large amounts. In other words, the pulse must rise and fall sharply in order to be as nearly rectangular in shape as possible.


1000 YD
6USEC
REFERENCE MARKS
8 USEC
REPETITION-RATE BLOCKING OSCILLATOR
FIRST COINCIDENCE BLOCKING OSCILLATOR
SECOND COINCIDENCE A TRIGGER BLOCKING OSCILLATOR
A TRIGGER
(SYNC PULSE)
1000 YARDS AFTER A TRIGGER
1000-YARD DELAYED
THIRD COINCIDENCE BLOCKING OSCILLATOR
2000 YARDS AFTER A TRIGGER
FOURTH COINCIDENCE AMPLIFIER
2000 YARDS AFTER A TRIGGER
MODULATOR TRIGGER
FIXED SYNCHRONIZING TRIGGER

12.314

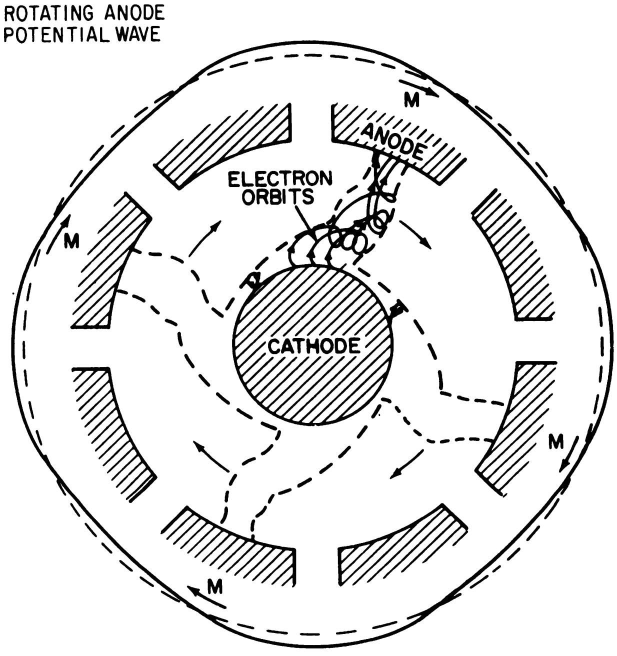
Figure 9-5.—Radar timing chart.

RF Oscillators

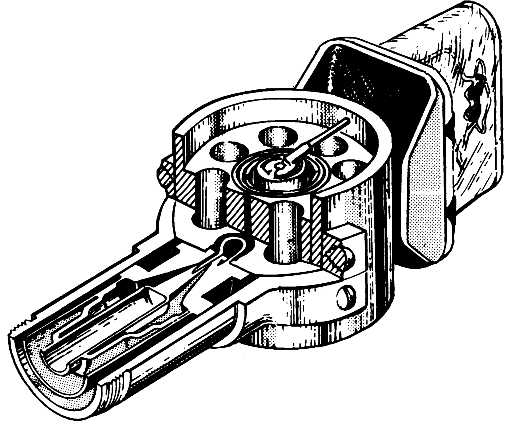
As stated earlier, the radar's transmitter generates and delivers pulses of rf energy to the antenna system. Because of the high frequencies needed by fire control radars, the rf oscillators in this topic are quite different in construction from those with which you are already familiar.

THE MAGNETRON OSCILLATOR.—The most common high-frequency oscillator used in gun fire control radars is a resonant-cavity magnetron. The frequency generated by the magnetron determines the wavelength of the radio waves that are radiated into space—the higher the frequency, the shorter the wavelength. Since short wave-lengths can be concentrated into a beam by a relatively small antenna, the wavelengths utilized in military applications are only a few centimeters long. In order to produce such short wavelengths, the high-frequency oscillator must generate voltages that alternate at a frequency of several billion cycles per second. The magnetron is well adapted to this high-speed task.

A magnetron consists primarily of a block of copper with resonant cavities inside. The magnetron is usually a diode with a cylindrical anode and an axial, filament-type cathode. A strong magnetic field from an external magnet is directed parallel to the filament. When a pulse voltage from the modulator excites the cathode, it causes electrons to flow to the anode.



ORBITS OF ELECTRONS OF DIFFERENT PHASES IN A CAVITY MAGNETRON



CUT-AWAY VIEW OF A CAVITY MAGNETRON

167.770

Figure 9-6.—The magnetron.

During the electrons' travel from the cathode to anode, the magnetic field causes them to alternately increase and decrease in velocity. When the electrons pass the cavities they impart energy to the cavities to start and sustain oscillations. The cavities are capable of sustaining a definite frequency, called the resonant frequency. The size of the cavity determines the frequency that is sustained—the smaller the cavity, the higher the frequency. A typical microwave cavity magnetron is shown in figure 9-6. The power output is obtained either by coupling loop or by a transformer section of a waveguide inserted into a cavity. The loop conveys the power generated inside the magnetron to the waveguide, and from there to the antenna to be sent out into space. (The waveguide is used to convey microwave (electrical) energy as wire conductors do at lower frequencies.)

THE KLYSTRON TUBE.—The klystron tube is a specially constructed electron tube using the properties of transit time and velocity modulation of the electron beam to produce microwave frequency operation. It can be used as an oscillator or an amplifier. The amplifier employs two or more cavities to produce the proper bunching of electrons, upon which its function and amplifying properties are based. The amplifier type of klystron can produce a large amount of power (megawatts) and can be used as an oscillator if proper feedback arrangements are made. However, the reflex klystron offers a simpler type of feedback arrangement and performs specifically as a special tube designed for oscillator operation alone. Although the power output of the reflex klystron is limited, it is adequate for receiving and test equipment functions and for low-power transmitters. Where high power is required, it can be achieved by using the reflex klystron as a master oscillator and the conventional amplifier type of klystron as a power amplifier. Since microwave radiation is limited to line-of-sight distances, the reflex klystron usually furnishes sufficient power for these relatively short rf transmission paths.

The operation of the klystron is based upon the development of velocity modulation of the electron beam; that is, the velocity of the electron beam is controlled to produce a grouping or bunching of electrons. These bunches of electrons are then passed through grids or cavities to produce oscillations at the desired frequency by direct excitation of the cavities.

A basic klystron (not the reflex type) is shown in figure 9-7. The electrons from the cathode are attracted to the accelerator grid (No. 1) which is at a positive potential with respect to the cathode. The accelerator grid may be a grid structure or an annular ring (cylinder or sleeve) through which the electrons pass unhindered. Assume that this attraction produces a constant-velocity electron beam, which is further attracted to the next electrode, the buncher grids (or cavity), and then to the next electrode, the catcher grids (or cavity), also at a higher positive potential. If the output from the catcher is fed back to the buncher, and if the proper phase and energy relations are maintained between the buncher and the catcher, the tube operates as an oscillator. The collector plate, which is also at a positive potential, serves only to collect the electrons which pass the catcher. Successful operation requires that the energy needed for bunching be less than that delivered to the catcher. Amplifying action is obtained because the electrons pass through the catcher in definite bunches or groups.

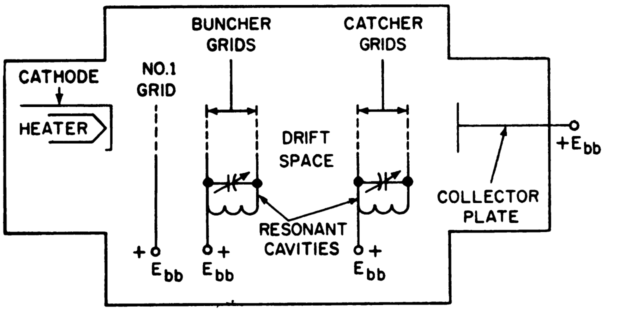


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Figure 9-7.—Basic klystron.

Bunching is produced by applying an alternating voltage to the buncher grids (produced by excitation of the buncher resonator by the passing electron beam). Assuming that a sine-wave voltage is produced and applied between the buncher grids, it is evident that on the positive alternation the buncher grid nearest the catcher effectively has its positive potential increased, and therefore further accelerates the electron flow. On the negative alternation, the same buncher grid voltage is made less positive and the electron stream is slowed. Since a continuous stream of electrons enters the bunching grids, the number of electrons accelerated by the alternating field between the buncher grids on one half-cycle of operation is equalled almost exactly by the number of electrons decelerated on the negative half-cycle. Therefore, the net energy exchange between the electron stream and the buncher is zero over a complete cycle of alternation, except for the losses that occur in the tuned circuit (cavity) of the buncher.

After passing through the buncher grids, the electrons move through the drift space in the tube with velocities which have been determined by their transit through the buncher grids. Since in a conventional klystron the drift space is free of any fields, at some point in this drift space the electrons which were accelerated catch up with those which were previously decelerated (in a prior passage) to form a bunch. The catcher grids are placed at this point of bunching (determined by frequency and transit time) to extract rf energy from the bunched electrons.

At the catcher a different situation exists. Since the electrons are traveling in bunches, spaced so that they enter the catcher field only when the oscillating circuit is in its decelerating half-cycle, more energy is delivered to the catcher than is taken from it. The remaining electrons in the beam pass through the grid and travel to the collector plate, where they are absorbed.

THE TRAVELING-WAVE TUBE (TWT).—The traveling wave tube (twt) is a high-gain, low-noise, wide-bandwidth microwave amplifier. Traveling-wave tubes are capable of gains of 40 decibels (db) or more, with bandwidths of over an octave. (A bandwidth of one octave is one in which the upper frequency is twice the lower frequency.) The tubes have been designed for frequencies as low as 300 megahertz (MHz) and as high as 50 gigahertz (GHz).

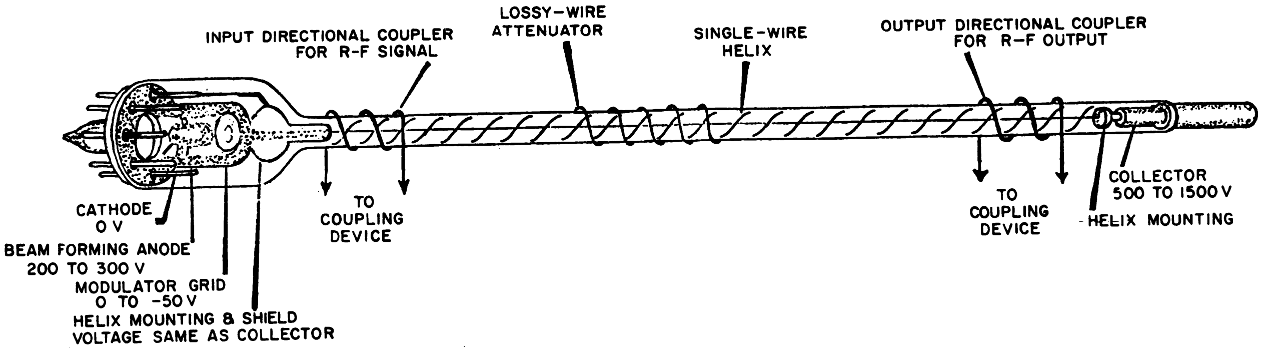
The primary use for the twt is voltage amplification (although high-power twt's, with characteristics similar to those of a power klystron, have been developed). Their wide-bandwidth and low-noise characteristics make them ideal for use as rf amplifiers in microwave and electronic countermeasures equipment.

Figure 9-8 is a pictorial diagram of a traveling-wave tube. The electron gun produces a stream of electrons which are focused into a narrow beam by an axial magnetic field, much the same as in a klystron tube. The field is produced by a permanent magnet or electromagnet (not shown) which surrounds the helix portion of the tube. The narrow beam is accelerated as it passes through the helix by a high potential on the helix and collector. The function of the helix is discussed later.

Whereas the electron beam in a klystron travels, for the most part, in regions free from rf electric fields, the beam in a twt is continually interacting with an rf electric field propagating along an external circuit surrounding the beam.

To obtain amplification, the twt must propagate a wave whose phase velocity is nearly synchronous with the d.c. velocity of the electron beam. It is difficult to accelerate the beam to greater than about one-fifth the velocity of light. Therefore, the forward velocity of the rf field, propagating along the helix, must be reduced to nearly that of the beam.

The phase velocity in a waveguide which is uniform in the direction of propagation is


INPUT DIRECTIONAL COUPLER FOR R-F SIGNAL
LOSSY-WIRE ATTENUATOR
SINGLE-WIRE HELIX
OUTPUT DIRECTIONAL COUPLER FOR R-F OUTPUT
CATHODE 0 V
BEAM FORMING ANODE 200 TO 300 V
MODULATOR GRID 0 TO -50 V
HELIX MOUNTING & SHIELD VOLTAGE SAME AS COLLECTOR
TO COUPLING DEVICE
TO COUPLING DEVICE
COLLECTOR 500 TO 1500 V
HELIX MOUNTING

179.728

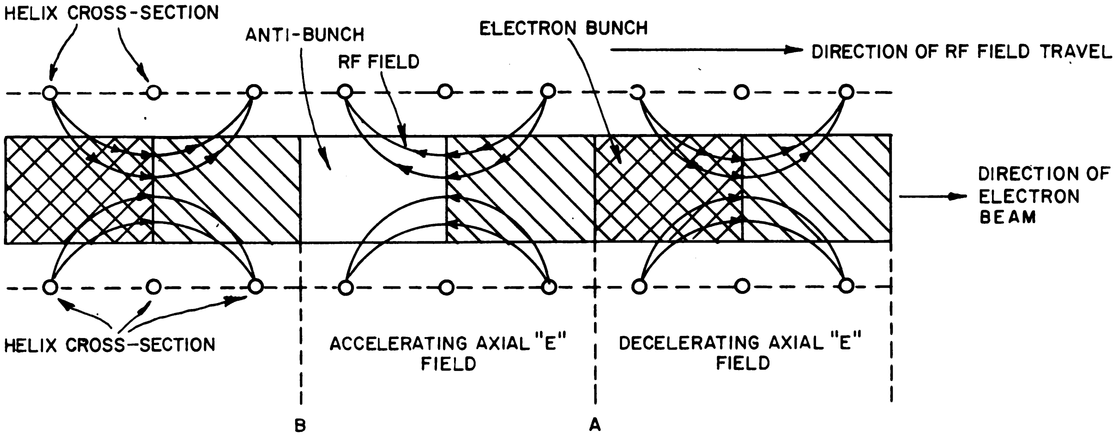
Figure 9-8.—Pictorial diagram of a traveling-wave tube.

always greater than the velocity of light. However, this velocity may be reduced below the velocity of light by introducing a periodic variation of the circuit in the direction of propagation. The simplest form of variation is obtained by wrapping the circuit in the form of a helix whose pitch is equal to the desired slowing factor.

As previously explained, the electron beam is focused and constrained to flow along the axis of the helix. The longitudinal components of the input signal's rf electric field, along the axis of the helix or slow-wave structure, continually interact with the electron beam to provide the gain mechanism of the twt. This interaction mechanism is pictured in figure 9-9. This figure illustrates the rf electric field of the input signal, propagating along the helix, infringing into the region occupied by the electron beam.

Consider first the case where the electron velocity is exactly synchronous with the circuit phase velocity. Here, the electrons experience a steady d.c. electric force which tends to bunch them around position A, and debunch them around position B. This action is due to the accelerating and decelerating electric fields, and is similar to velocity and density modulation, previously discussed. In this case, as many electrons are accelerated as are decelerated; hence, there is no net energy transfer between the beam and the rf electric field. To achieve amplification, the electron beam is adjusted to travel slightly faster than the rf electric field propagating along the helix. The bunching and debunching mechanisms just discussed are still at work, but the bunches now move slightly ahead of the fields on the helix. Under these conditions more electrons are in the decelerating field to the right of A than are in the accelerating field to the right of B. Since more electrons are decelerated than are accelerated, the energy balance is no longer maintained. Thus, energy transfers from the beam to the rf field, and the field grows.

Fields may propagate in either direction along the helix. This leads to the possibility of oscillation due to reflections back along the helix. This tendency is minimized by placing resistive material near the input end of the slow-wave structure. This resistance may take the form of a lossy-wire attenuator (fig. 9-8) or a graphite coating placed on insulators adjacent to the helix. Such lossy sections completely absorb any backward traveling wave. The forward wave is also absorbed to a great extent, but the signal is carried past the attenuator by the bunches of electrons. These bunches are not affected by the attenuator, and, therefore, reinstitute the signal on the helix after they have passed the attenuator.


HELIX CROSS-SECTION
ANTI-BUNCH
RF FIELD
ELECTRON BUNCH
DIRECTION OF RF FIELD TRAVEL
DIRECTION OF ELECTRON BEAM
HELIX CROSS-SECTION
ACCELERATING AXIAL "E" FIELD
DECELERATING AXIAL "E" FIELD
B
A

179.729

Figure 9-9.—Helix field interaction.

A forward wave traveling-wave tube may be constructed to serve as a microwave oscillator. Physically, a twt amplifier and oscillator differ in two major ways. The helix of the oscillator is longer than that of the amplifier, and there is no input connection to the oscillator.

The operating frequency of a twt oscillator is determined by the pitch of the tube's helix. The oscillator may be tuned, within limits, by adjusting the operating potentials of the tube.

The electron beam, passing through the helix, induces an electromagnetic field in the helix. Although initially weak, this field, through the action previously described, causes bunching of succeeding portions of the electron beam. With the proper potentials applied, the bunches of electrons reinforce the signal on the helix. This, in turn, increases the bunching of succeeding portions of the electron beam. The signal on the helix is sustained and amplified by this positive feedback resulting from the exchange of energy between the electron beam and the helix.

The Modulator

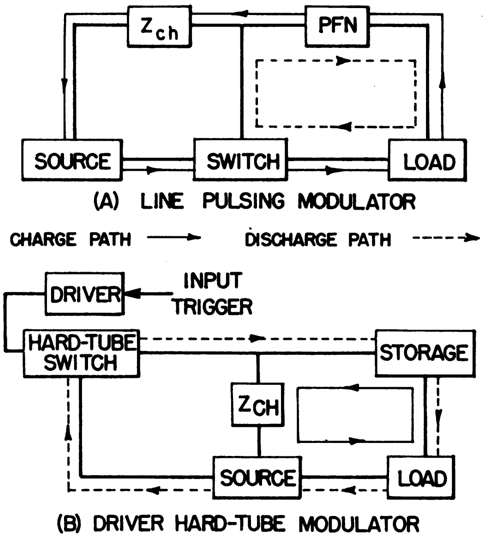
A magnetron is a self-excited oscillator. It is necessary for the modulator or pulse generator to modulate the full output of the tube. The term modulator is used to refer to the circuits which control the application of high voltage to the magnetron. Since the expression modulate means to shape as well as to control, the modulator refers to the pulse-forming network as well as the driver circuitry which produces the pulse that is delivered to the control grid of the modulator stage.

Modulators are also called pulsers or keyers to denote their circuit function. There are two basic types of pulsers—hard-tube and line pulsers. The term hard-tube refers to a vacuum tube which controls a capacitor discharge. The pulse is formed in a driver unit and applied to the control grid of the vacuum tube which acts as a switch to control the pulse duration. In line type pulsers, a lumped-constant transmission line serves as both the energy storage driver and the pulse-shaping element. This is called a pulse-forming network (PFN).

The block diagrams of two types of modulator systems are illustrated in figure 9-10. The LINE-PULSING MODULATOR (fig. 9-10A) consists of the following components:

1. SOURCE—Provides high voltage to the storage element in the modulator.
2. Z_{ch}—The total impedance in the storage network charge path.
3. SWITCH—Allows the storage network to charge when open; allows the storage network to discharge when closed.
4. PULSE-FORMING NETWORK (PFN)—Stores the high voltage provided by the source; also determines the shape and width of the high voltage pulse applied to the load.
5. LOAD—Primary winding of the pulse transformer.

The DRIVER HARD-TUBE MODULATOR (fig. 9-10B) differs from the line-pulsing type in many respects. (A hard tube is an electron tube which has been evacuated to approach a perfect vacuum, as opposed to a tube which contains an appreciable amount of gas (soft tube).) Although the source load (Z_{ch}), the source, and the load are similar to the line-pulsing type, the storage network in the hard-tube system does



179.660

Figure 9-10.—Two types of modulators.

not shape the output pulse. The hard-tube modulator consists of the following components:

1. Z_{ch} SOURCE LOAD–Same as in the line pulsing type.
2. STORAGE NETWORK–Usually a large capacitor (does not determine pulse width).
3. HARD-TUBE SWITCH–Controls the charge and discharge of the storage unit. When the switch tube is cut off, the storage unit charges; when the switch tube conducts, the storage unit discharges.
4. DRIVER–Input is a trigger from the master timer; output is a high voltage pulse used to drive the switch tube into conduction. Since the width of this pulse determines how long the switch tube will conduct, the driver pulse width will determine the width of the high voltage pulse applied to the load.

Whichever type is employed, the modulator furnishes a high-value voltage to the rf oscillator for the predetermined pulsing time, and is responsible for the pulse duration time of the rf oscillator.

After the pulse-forming network has been charged, some method of switching must be provided to allow the pulse-forming network to discharge through the load. The switch must be able to handle a high pulse-repetition frequency and pass a current flow which may exceed 100 amperes. The switch must also provide accurate control of the on and off time interval.

One method of switching is illustrated in figure 9-11A. In this case, a hydrogen thyratron is used as the switching device. During t_1 (fig. 9-11B) the thyratron is not conducting, and the pulse-forming network (line) charges through L_{ch} and the charging diode. The pulse-forming network charges to approximately 1.8 times the source voltage. At the start of t_2, a trigger pulse, which corresponds in time with the master timer trigger, is applied to the grid of the thyratron. The thyratron is driven into conduction, allowing the line to discharge into the load. Since the line impedance (Z_0) is closely matched to the impedance of the load Z_R, one-half of the line voltage is dropped across the load.

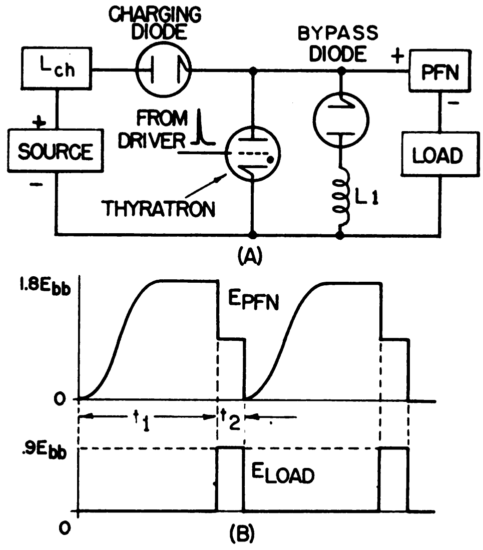


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Figure 9-11.–Modulator using a thyratron switch.

At the end of t_2, the line voltage decreases rapidly and the thyratron deionizes. The width of the pulse appearing across the load is determined by the two-way delay time of the line.

The bypass diode and inductor L_1 are connected in a shunt with the thyratron to prevent inverse charging of the line. If an inverse charge is present on the line, the bypass diode conducts, providing a discharge path through the inductor. The discharge current produces a magnetic field around L1. When the discharge current stops, the field around L1 collapses, causing a slight charge of the proper polarity in the pulse-forming network.

Pulse Transformer

The load (pulse transformer primary) is connected to the line or storage circuit (fig. 9-12). The secondary of the pulse transformer is connected to the cathode of a magnetron (master oscillator power amplifier). The pulse transformer is used to step up the high-voltage pulse from the pulse-forming network and provide impedance matching between the magnetron and the line. The pulse transformer

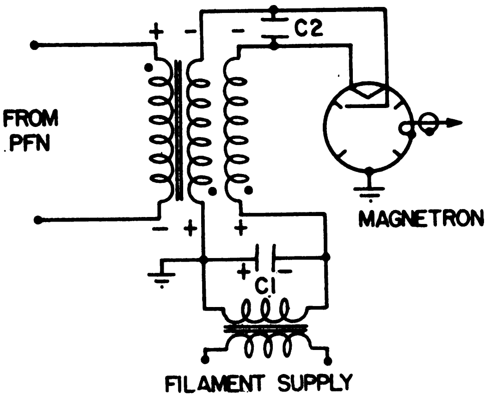

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Figure 9-12.—Bifilar secondary.

design is critical because of the high-frequency components present in the output pulse. The core is composed of thin laminations of ferro-magnetic material, usually silicon steel. Close coupling between primary and secondary reduces leaking inductance to preserve the steep leading edge of the input pulse. Low interwinding capacitance is desired to prevent high-frequency oscillations. Close coupling is attained between primary and secondary by winding the primary directly on the secondary and by using the same leg of the core for both windings. The secondary is usually a BIFILAR WINDING.

The bifilar winding secondary is illustrated in figure 9-12. It is made up of two insulated conductors, wound side by side so that exactly the same voltage is induced in each. The bifilar winding acts as two secondaries which have equal in-phase voltages induced in them. The bifilar winding permits the use of a filament secondary without high-voltage insulation.

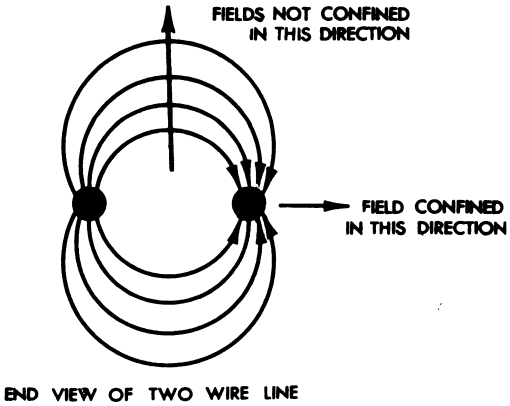
Bypass capacitors, C1 and C2, are often used so that pulse current flows directly to the bifilar winding, without affecting the filament circuit.

Transmission Lines

The carrier frequency of fire control radar is in the superhigh-frequency band, well within the microwave region. Although electrical energy at microwave frequencies obeys the fundamental laws of electricity, its behavior is unique. The ordinary two-wire transmission line is inefficient at these frequencies. Therefore, a waveguide is used. A waveguide is a metallic pipe which is used to transfer superhigh-frequency electromagnetic energy. The high frequencies employed by fire control radar transmitters require this unique, but very practical device.

Fundamentally, there are two methods of transferring electromagnetic energy. One method is by means of current flow through conductors and the other is by movement of electromagnetic fields. The transfer of energy by these two means may appear to be unrelated. However, they are not. Consider the two-wire conductors as elements which guide electromagnetic fields from one point to another. The current which flows through the conductors is the result of the moving electromagnetic field.

At microwave frequencies, two-wire conductors are a poor means of transferring electromagnetic energy. This is because they do not confine the energy. The energy escapes by radiation (like an antenna), as illustrated in figure 9-13. However, electromagnetic fields may be confined when one conductor is


FIELDS NOT CONFINED IN THIS DIRECTION
FIELD CONFINED IN THIS DIRECTION
END VIEW OF TWO WIRE LINE

179.672

Figure 9-13.—Fields confined in two directions but not in the other two.

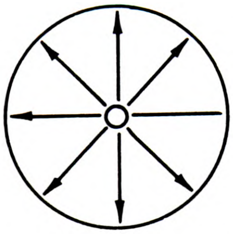


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Figure 9-14.—Fields confined in all directions.

extended around the other to form a coaxial cable (fig. 9-14).

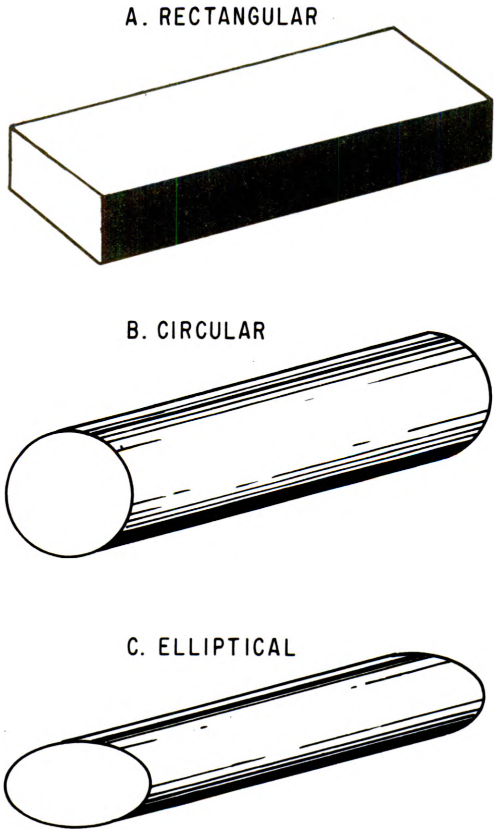
Energy in the form of electromagnetic fields may be transferred very efficiently through a line that does not have a center conductor (waveguide). A waveguide actually guides the electromagnetic wave of energy down the metallic pipe. The electromagnetic field configuration in a waveguide is different from that of a coaxial cable, due to the missing center conductor. A waveguide may be rectangular, circular, or elliptical, as shown in figure 9-15.

More information on waveguides may be obtained from *Navy Electricity and Electronics Training Series (NEETS), Module 10, Introduction to Wave Propagation, Transmission Lines and Antennas.*

The waveguide is used to connect the transmitter to the antenna, and the antenna to the receiver. All other transmissions of electromagnetic energy are by means of conventional conductors and coaxial cables.

To help you understand the overall operation of the radar, let us discuss the operation of the duplexer and the antenna feeder system.

The high-power rf pulse from the magnetron is coupled into the waveguide, which in turn feeds it to the antenna system. When the rf energy is coupled into or out of a waveguide the impedance of all the elements must be matched to obtain a maximum transfer of energy. If the impedance is not properly matched, some of the energy will not be absorbed by the load and will be reflected back toward the original source. The reflected rf energy will create a wave traveling in the opposite direction. If the frequency of the original rf energy, (called the incident wave) and the impedance of the mismatch are constant, the reflected wave will appear to be standing still in the transmission line. Thus, a standing wave of reflected energy is trapped in the line. Standing waves represent wasted power in the radar. The ratio of the maximum voltage on the line to the minimum voltage is called the STANDING WAVE RATIO, or swr, of the line. This ratio indicates the amount of mismatch of the lead impedance. Where there is no mismatch the swr is equal to one, or unity. For efficient operation, the value



166.238

Figure 9-15.—Waveguides.

of the swr must be small. SWR is discussed in more detail later in this chapter.

The transmission line should have a characteristic impedance that is equal to the antenna's impedance. The antenna is the load on the line. Where this occurs, all the power is absorbed by the antenna and none is reflected back into the line. There is, however, a marked change in impedance with a change in frequency. The rf magnetron has a tendency to drift slightly in frequency; also, its frequency is tunable. Therefore, impedance-matching devices are included in the waveguide. The impedance of the transmission line is adjusted to match the impedance of the generator, the line, and the load.

The design of the transmission line is further complicated by the fact the antenna is used for both transmitting and receiving. Consequently, the rf line from the antenna must be connected to the transmitter and to the receiver. If the receiver were not protected from the powerful rf pulse that occurs when the radar is transmitting, crystals in the receiver's mixer assembly would be destroyed. On the other hand the receiver must be able to respond to very weak echo signals. When the radar is receiving, we cannot afford to lose some of the echo signal by having it travel down the branch of the rf line going to the magnetron. This would result in weaker targets not being detected. Obviously, some sort of switching arrangement is necessary.

Duplexer

An electromechanical switch could be used to shift the rf line between the transmitter and the receiver, but it would have to be a special switch. The operation of the switch must be synchronized with the prr of the radar so that the proper channel is blocked at the proper time. Since the prr of fire control radars is over 1,000 cycles per second, an electromechanical switch is impractical.

The switching device makes it possible for the transmitter and the receiver to use the same antenna. This is called a duplexer. The duplexer consists of sections of waveguide and transmit-receive (tr) tubes. It is the tr tubes that provide the fast switching action of the duplexer.

THE TR TUBE–A tr tube (fig. 9-16) is a special gas tube with a spark gap. A spark gap is a gap between two electrodes, across which a potential difference may exist. When the potential difference is high enough, the tube fires. This produces a short across the gap. The operation of a tr tube is comparable to the operation of the common neon lamp used in the fire control switchboard. The width of the gap determines the potential difference needed to cause the tube to fire. In a radar, the transmitted rf energy causes the tube to fire. Normal returned rf signals, however, are too weak to cause the tube to fire.

Figure 9-17 shows a simple duplexer with a single tr tube in the branch of the waveguide going to the receiver. When the magnetron oscillates, it produces high-power rf energy. The transmitter's rf energy causes the tr tube to conduct and short out across the waveguide to the receiver. The short circuit protects the receiver from the transmitted pulse by effectively closing this branch to all rf energy except that necessary to keep the tr tube firing. But before the tube can fire, a small amount of the rf energy enters the receiver. It is this rf energy that produces the transmitter pulse that is seen on the radar indicators. To limit the amount of rf energy allowed to enter the

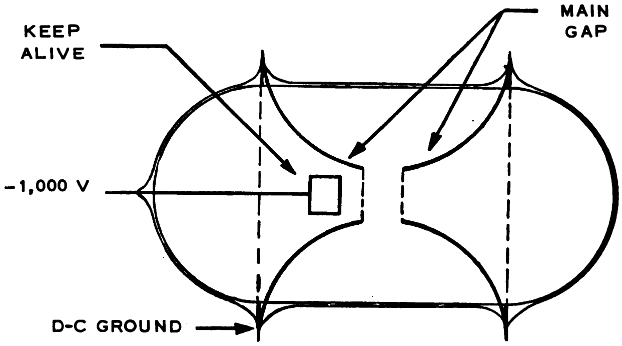


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Figure 9-16.—A tr tube with a keep-alive electrode.

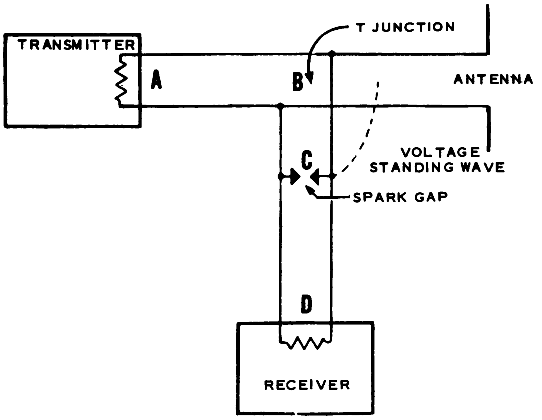

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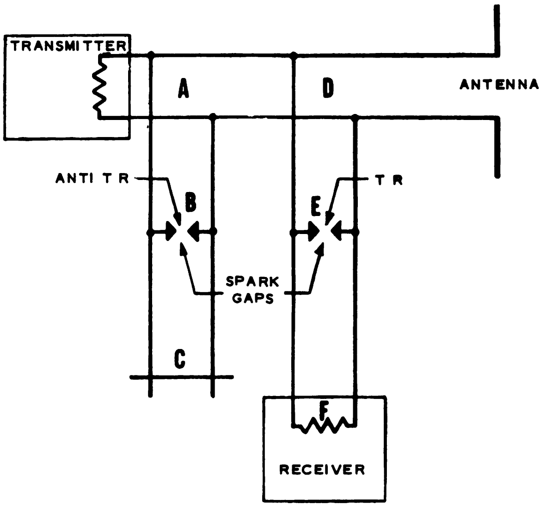
Figure 9-17.–An rf system using a tr tube.



67.20
Figure 9-18.–An rf line with tr and atr tubes.

receiver before the tr tube fires, a high negative potential is applied to one of the tube's electrodes. This voltage is called the "keep-alive" voltage and is used to maintain the gas in the tube in a state of partial ionization. Thus, a short is produced more quickly when transmission is started.

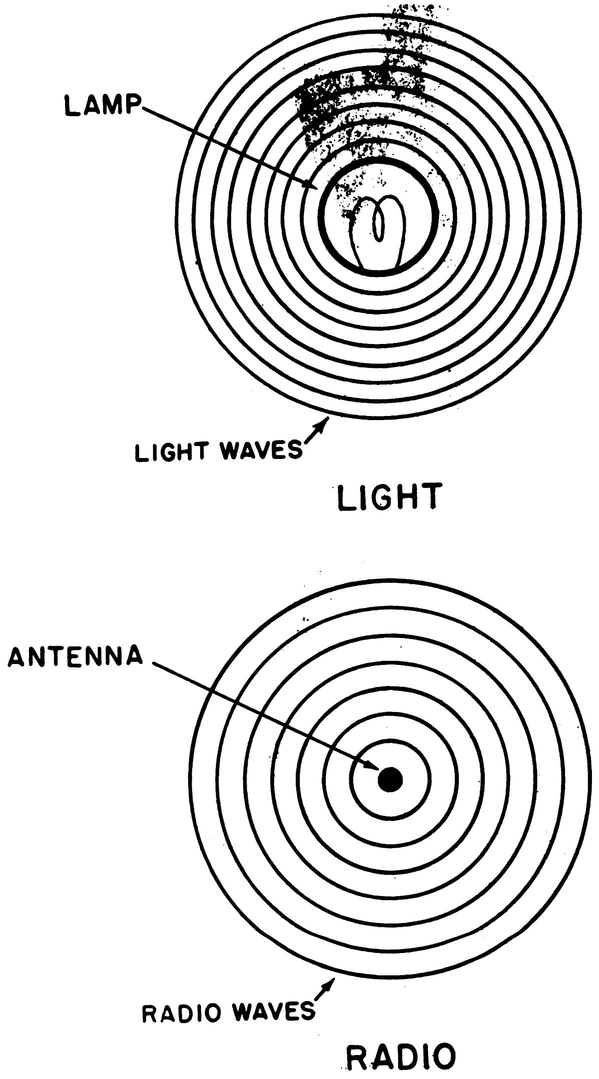
THE ATR TUBE.–When the magnetron stops oscillating, the short across the tr tube is removed and the duplexer is returned to its receive position with the receiver branch of the waveguide open to the antenna. In the simple duplexer shown in figure 9-17, the transmitter has not been disconnected from the antenna and some of the returned rf energy could enter the transmitter. To ensure that all the returned energy enters the receiver, a second tube called the atr (anti-tr) is used. This tube is located in a waveguide branch connected to the main line between the transmitter and the receiver (fig. 9-18).

The atr tube operates in the same manner as the tr tube. The rf energy from the transmitter shoots the gap and fires the tube. The shorted atr tube closes the branch from the rf energy. When the magnetron stops oscillating, the short across the atr tube is removed. The atr waveguide branch is a critical length shorted at its end. This short presents a very high impedance to the returned rf energy traveling down the waveguide towards the transmitter. The high impedance effectively closes the path to the transmitter for the returned rf energy, and it all goes into the receiver.

ANTENNA

The radar transmitter produces the rf energy and the antenna radiates this energy into space. The radiated energy tends to spread out equally in all direction. However, by mounting a suitable reflector behind the antenna, a large part of the radiated energy can be formed into a relatively narrow beam.

Figure 9-19 compares the radiation from a radio antenna with that from a lamp. Both light waves and radio waves are electromagnetic radiations; the two are believed to be identical, except in frequency of oscillation. From both sources, energy spreads out in the form of spherical waves. Unless they meet some obstruction, these waves travel outward indefinitely at the speed of light. Because of their much higher frequency, light waves have much shorter wavelengths than radio waves. This is illustrated in figure 9-19, but it cannot be shown accurately to scale. The wavelength of a



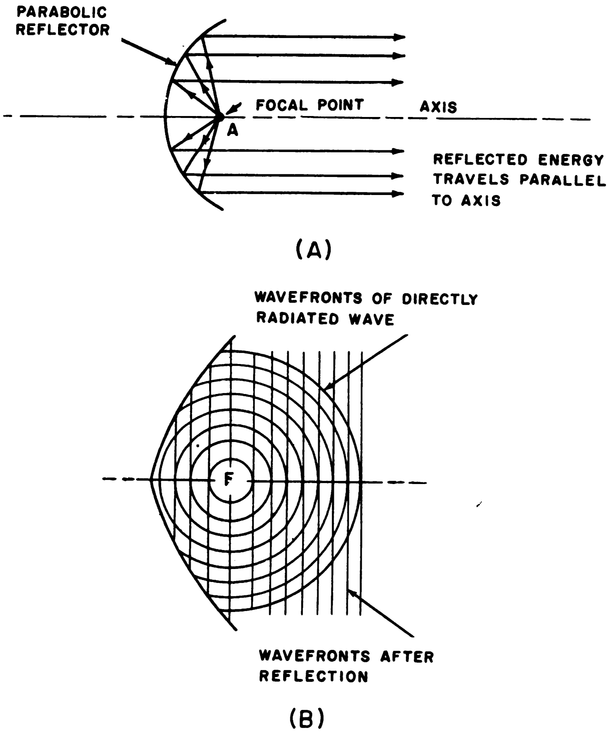
144.38
Figure 9-19.—Radiation, unrestricted, from a lamp and a radio antenna.

radar transmission may be measured in centimeters; the wavelength of light ranges from about three to seven ten-thousandths of a millimeter.

You are, of course, familiar with the use of polished reflectors to form beams of light. An automobile headlight is an example of this, although it produces a fairly wide beam. A spotlight produces a more narrow beam.

A type of reflector generally employed in fire control radars is the parabolic dish. It is similar in appearance to the reflector used in an automobile headlight. One of the important advantages of radar operation in the microwave region of the electromagnetic spectrum is that microwaves have properties and characteristics similar to those of light. This permits the use of well-known optical design techniques.

The action of the reflecting surface of the reflector is a result of its parabolic shape and the fact that the rays striking and reflecting from the metallic surface make equal angles with the surface at the point of reflection. This action is illustrated in figure 9-20. In A of the figure, consider that the focal point is a feedhorn radiator and is a point source of energy. Electromagnetic energy is emitted from a point source in spherical waves, like ripples that fan out from a pebble thrown into a pond of still water. The primary purpose of the parabolic reflector is to change the spherical wavefronts of the radiated energy into flat (plane) waves and


PARABOLIC REFLECTOR
FOCAL POINT
AXIS
A
REFLECTED ENERGY TRAVELS PARALLEL TO AXIS
(A)
WAVEFRONTS OF DIRECTLY RADIATED WAVE
F
WAVEFRONTS AFTER REFLECTION
(B)

1.49:25.266
Figure 9-20.—Principles of the parabolic reflector.

focus them into a circular beam. Part B of figure 9-20 shows spherical wavefronts coming from a radiated feedhorn at the focal point of a parabolic reflector. As the waves strike the reflector they are straightened and concentrated into a narrow circular beam of energy containing parallel, flat wavefronts.

When the radar antenna is receiving reflected energy, the incoming rays are concentrated and focused on the feedhorn only when they enter the dish in perfectly parallel rays, as shown in B of figure 9-20. The waves reflected from the target, under ideal conditions, are parallel when they are transmitted in this form. Therefore, it can be said that in any antenna system the transmitting and receiving patterns are essentially the same. For this reason, one antenna can be used for transmission and reception. The parabolic reflector produces a "pencil beam" in which most of the energy is confined to a small cone of the nearly circular cross section. The concentration of the energy into a beam increases the amount of radiation illuminating a target.

But no radar can produce an ideal beam of parallel rays. For one thing, the end of the waveguide is large, compared to the ideal point source. For another, a reflector of practical size is not sufficiently large compared with the wavelength of the radiated energy. A radar beam, therefore, diverges and forms a lobe, like the one in figure 9-21. This is the main lobe or beam. It should be clearly understood that such a lobe is merely a convenient way of representing the beam on a paper; it is in no sense a "picture"of the beam. Some of the radiated energy is scattered outside the main lobe and forms side lobes, usually of lesser intensity and much shorter range. They are undesirable lobes that exist in close proximity to the transmitter. Also, the radiation does not end abruptly at a certain distance from the transmitter, as the diagram implies. The lobe, if it can be pictured in three dimensions, can be thought of as a surface, all parts of which receive an equal amount of energy. This can be considered the minimum energy that is useful for the purpose of target tracking. The lobe in figure 9-21 is not drawn to scale. The diameter of the reflector is in the order of 5 feet; the length of the lobe may be from 20 to 50 miles. Its useful width may be 4° or 5°. At any given distance from the transmitter, the signal is strongest along the axis of the lobe.

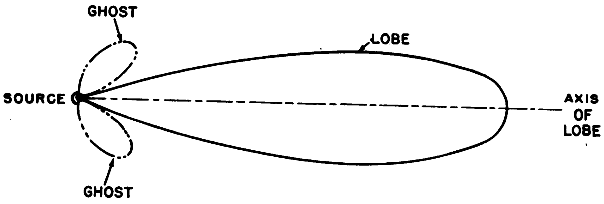


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Figure 9-21.—Lobe formation of a radar beam.

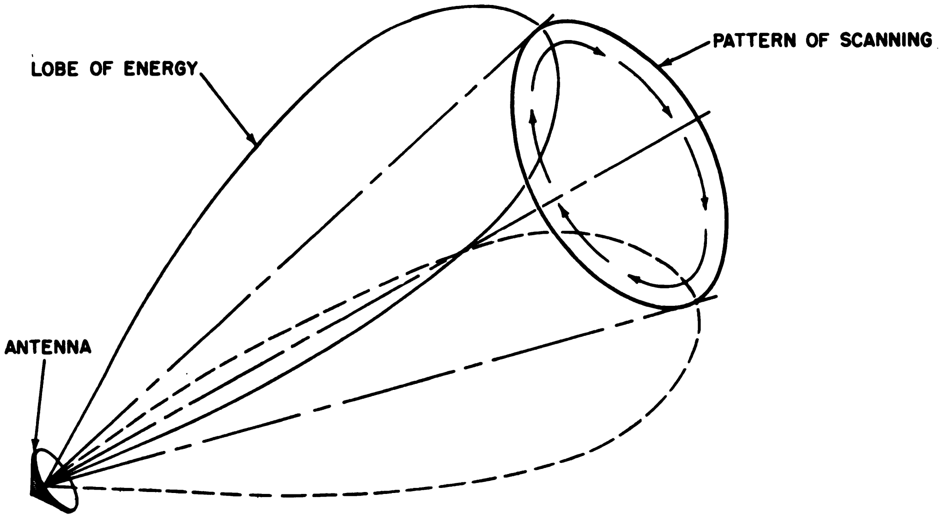
Target tracking may be accomplished by nutating the lobe (moving rf feed point) in a small circle around the focal point of a fixed parabolic reflector. This scanning effect, depicted in figure 9-22, is studied next in this chapter.

METHODS OF SCANNING

The two basic methods of accomplishing scanning are mechanical and electronic. In mechanical scanning, the beam can be moved in various ways. The entire antenna can be moved in the desired pattern; the feeder can be moved relative to a fixed reflector; or the reflector can be moved relative to a fixed source. In electronic scanning, the beam is effectively moved by such means as switching between a set of feeder sources, varying the phasing between elements in a multielement array, or comparing the amplitude and phase differences between signals received by a multielement array. A combination of mechanical and electronic scanning sources is also used in varying the phasing between elements in a multielement array, or comparing the amplitude and phase differences between signals received by a multielement array. A combination of mechanical and electronic scanning is also used in some antenna systems.

MECHANICAL SCANNING

A common form of scanning for target tracking is conical scanning. This is generally



167.765

Figure 9-22.—A nutating lobe.

accomplished mechanically by nutating the rf feed point.

Nutation

Nutation is difficult to describe in words, but easy to demonstrate. Hold a pencil in two hands. While holding the eraser end as still as possible, swing the point through a circle. This motion of the pencil is nutation. (The pencil point corresponds to the open, or transmitting, end of the waveguide antenna.) The important thing is that polarization of the beam is not changed during the scanning cycle. This means that the axis of the moving feed must not change horizontal or vertical orientation while the feed is moving. The movement might be compared to that of a ferris wheel; the position of the seats must remain the same regardless of the position of the wheel.

Nutating Waveguide

As stated earlier, the waveguide is a metal pipe, usually rectangular in cross section, which is used to conduct the rf energy from the transmitter to the antenna. The open end of the waveguide faces the concave side of the reflector, and the rf energy it emits is bounced from the reflector surface.

A conical scan can be generated by nutation of the waveguide. In this process, the axis of the waveguide itself is moved through a small conical pattern. This three-dimensional movement in an actual installation of the waveguide is fast and of small amplitude. To an observer, the waveguide appears merely to be vibrating slightly.

Nutating Lobe

By movement of either the waveguide or the antenna it is possible to generate a conical scan pattern, as shown in figure 9-22. The axis of the radar lobe is made to sweep out a cone in space; the apex of this cone is, of course, at the radar transmitter antenna or reflector. At any given distance from the antenna, the path of the lobe axis is a circle. Within the useful range of the beam, the inner edge of the lobe at all times overlaps the axis of scan.

Now assume that a conically scanned beam is used for target tracking. When the target is on the scan axis, the strength of the reflected signals remains constant (or changes gradually as the range changes). But when the target is slightly off the axis, the amplitude of the reflected signals changes rapidly and periodically. For example, when the target is ABOVE the scan axis, the reflected signals are of maximum strength as the lobe sweeps through the highest part of its cone. They quickly decrease to minimum strength as the lobe sweeps through the lowest part. Information on the instantaneous position of the beam relative to the scan axis and on the strength of reflected signals can be fed to a computer. This computer in the radar may be called angle tracking, angle servocircuit, or angle error detector. When the target moves off the scan axis, the computer instantly determines the direction and amount of antenna movement required to continue tracking. The computer output can be used to control servomechanisms that move the antenna, so the target is tracked accurately and automatically.

ELECTRONIC SCANNING

Electronic scanning can accomplish lobe motion more rapidly than, and without the inherent disadvantages of, the mechanical systems. Electronic scanning, however, generally cannot cover as large a volume in space. For this reason, it is sometimes combined with mechanical scanning in particular applications.

With monopulse or simultaneous lobing, all range, bearing, and elevation angle information of a target is obtained from, as the name implies, a single pulse.

A tracking radar of this type normally produces a narrow circular beam of pulsed rf energy at a high pulse-repetition rate. Each pulse is divided into four signals which are equal in amplitude and phase. The four signals are radiated at the same time from each of four feedhorns grouped in a cluster. The radiated energy is focused into a beam by a microwave lens. Energy reflected from targets is refocused by the lens into the feedhorns. The amount of the total energy received by each horn will vary, depending on the position of the target relative to the beam axis. This is illustrated in figure 9-23 for four targets at different positions with respect to the beam axis. Be sure to notice, and remember, that a phase inversion takes place at the microwave lens similar to the image inversion in an optical system.

The amplitude of returned signals received by each horn is continuously compared with those received in the other horns, and error signals are generated which indicate the relative position of the target with respect to the axis of the beam. Angle servocircuits receive these error signals and correct the position of the radar beam to keep the beam axis on target.

The traverse (train) signal is made up of signals from the sum of horns A and C and from the sum of horns B and D. By waveguide design, the sum of B and D is made 180° out of phase with the sum of A and C. These two are combined and the traverse signal is the difference of $(A + C) - (B + D)$. Since the horns are positioned as shown in figure 9-23, the relative amplitudes of the horn signals give an indication of the magnitude of the traverse error. The elevation signal consists of the signals from horns C and D added 180° out of phase with A and B, that is, $(A + B) - (C + D)$. The sum or range signal is composed of signals from all four feedhorns added together in phase. It provides a reference from which target direction from the center of the beam axis is measured. The range signal is also used as a phase reference for the traverse and elevation error signals.

The traverse and elevation error signals are compared in the radar receiver with the range or reference signal. The output of the receiver may be positive or negative pulses, the amplitude of which is proportional to the angle between the beam axis and a line drawn to the target. The polarity of the output pulses indicates whether the target is above or below, or to the right or to the left of the beam axis. Of course, if the target is directly on the line of sight, the output of the receiver is zero, and no angle tracking error is produced.

An important advantage of a monopulse tracking radar over one using conical scan is that the instantaneous angular measurements are not subject to errors caused by target scintillation

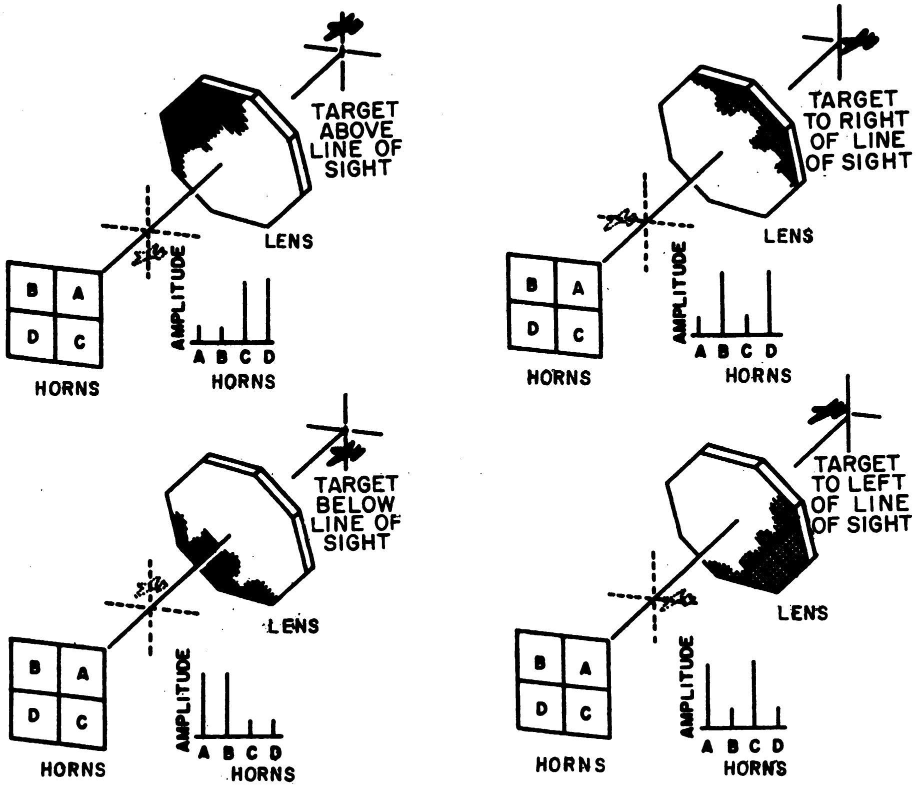


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Figure 9-23.—Monopulse scanning-amplitude changes of received energy with target position.

(rapid fluctuation). (As the target maneuvers or moves, the radar beams bounce off different areas of the target and cause random reflectivity, which may lead to tracking errors.) A monopulse tracking radar is not subject to this error because each pulse provides an angular measurement without regard to the rest of the pulse train; no cross-section fluctuations can affect the measurement.

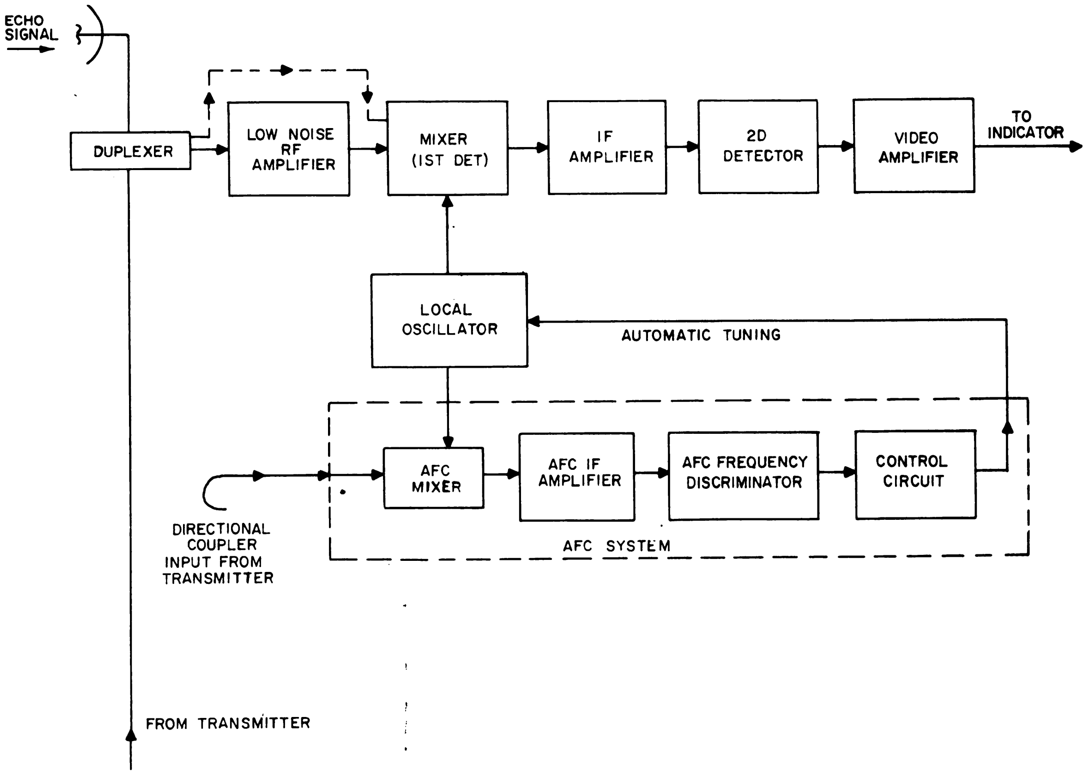
An additional advantage of monopulse tracking is that no mechanical action is required, such as a whirling scanner, while trying to do precise tracking.

RECEIVER

The rf echo pulses reflected by a distant object are similar to the transmitted pulses discussed previously, but are considerably diminished in amplitude. These minute signals are amplified and converted into video pulses by the receiver. A voltage amplification in the order of 10^{10} is required to produce a video pulse of sufficient amplitude to intensify the beam of a crt. The receiver must accomplish this amplification with minimum introduction of noise voltage.

The superheterodyne receiver is used exclusively in microwave systems. A simple block diagram of a microwave receiver based on the superheterodyne principle is shown in figure 9-24. The echo signal enters the system via the antenna shown in the upper left-hand corner of figure 9-24. It passes through the duplexer (tr and atr) and is amplified by the low-noise rf amplifier.

When external noise is negligible, the noise generated by the input stage of the receiver



179.732

Figure 9-24.—Microwave receiver based on the superheterodyne principle.

largely determines the receiver sensitivity. In early radar receivers and some present-day receivers, an rf amplifier is not used and the mixer is the first stage (as indicated by the dashed path in fig. 9-24). The function of the mixer stage, or first detector, is to translate the rf to a lower intermediate frequency, usually 30 or 60 MHz. This is accomplished by heterodyning the returning rf signal echo with a local oscillator signal in a nonlinear device (mixer) and extracting the signal component at the difference frequency (IF). Using the intermediate frequency makes it easier to obtain the necessary gain, than using the higher rf. It is also easier to develop the response function (or bandpass characteristic) of the receiver IF stages.

The second detector, which is sometimes an electron tube but more often a crystal rectifier, extracts the video modulation from the carrier. The modulation is amplified in the video stages to a level high enough to operate the indicator or display devices.

Automatic Frequency Control (AFC)

The afc system (fig. 9-24) normally employed to keep the receiver in tune with the transmitter is known as a DIFFERENCE – FREQUENCY SYSTEM. In this system, a portion of the transmitter signal is coupled into the afc mixer and is heterodyned with the local oscillator (l.) signal. When the transmitter and receiver are correctly in tune, the resultant difference frequency is at the correct IF. When the receiver is not in tune with the transmitter, the difference frequency is not correct. Any deviation from the correct IF signal is detected by the afc frequency discriminator, which, in turn generates an error voltage with a magnitude that is proportional to the deviation from the correct IF and with a polarity that determines the direction of the error. The error voltage corrects the frequency of the local oscillator common to both the receiver mixer and the afc mixer.

Local Oscillator

As pointed out earlier, most receivers use 30 or 60 MHz intermediate frequencies. An important factor in receiver operation is the tracking stability of the local oscillator, which generates the frequency that beats with the incoming signal to produce the IF. For example, if the local oscillator frequency were 3000 MHz, a frequency shift of as much as 0.1 percent would be a 3 MHz frequency shift. This is equal to the bandwidth of most receivers and would cause a considerable loss in gain.

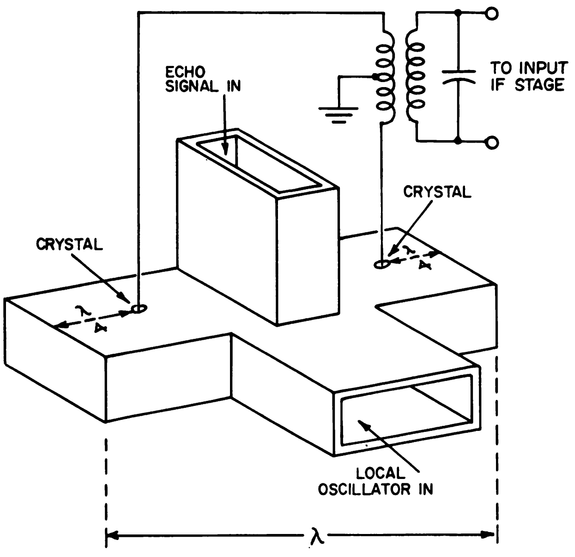
In receivers which use crystal mixers, the power required of the local oscillator is small, being only 20 to 50 milliwatts (mW) in the 4000 MHz region. Due to the very loose coupling, only about 1 milliwatt actually reaches the crystal.

Another requirement of a local oscillator is that it must be tunable over a range of several megahertz. This is to compensate for changes in the transmitted frequencies and in its own frequency. It is desirable that the local oscillator have the capability of being tuned by varying the voltage applied to it.

Because the reflex klystron meets the above requirements, it is used as a local oscillator in microwave receivers.

Balanced Mixer

One type of mixer which cancels local oscillator noise is the BALANCED, or HYBRID, MIXER (sometimes called the MAGIC TEE). Figure 9-25 illustrates this type of mixer. In hybrid mixers, crystals are inserted directly into the waveguide. The crystals are located one-quarter wavelength from their respective short-circuited waveguide ends. This is a point of maximum voltage along a tuned line. The crystals are also connected to a balanced transformer, the secondary of which is tuned to the desired IF. The local oscillator signal is introduced into the waveguide local oscillator arm and distributes itself as shown in figure 9-26A. Observe that the lo (local oscillator) signal is the same phase for each crystal. The echo signal is introduced into the echo signal arm of the waveguide and is of different phases for each crystal, as illustrated in figure 9-26B. The resulting fields are illustrated in figure 9-26C.

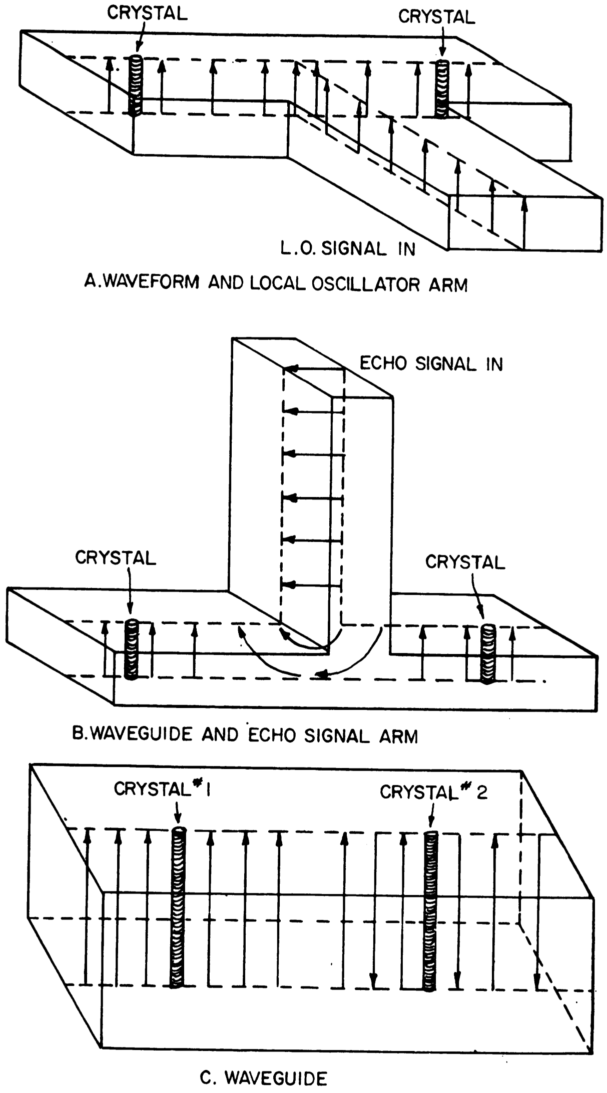


67.31

Figure 9-25.—Balanced hybrid crystal mixer.

Since there is a difference in phase between the echo signals applied across the two crystals, and because the signal applied to the crystals from the lo is in phase, a condition exists where both signals applied to crystal #1 are in phase, and the signals applied to crystal #2 are out of phase. This means that an IF signal of one polarity is produced across crystal #1 and an IF signal of the opposite polarity is produced across crystal #2. When these two signals are applied to the balanced output transformer (fig. 9-25), they add. Outputs of the same polarity cancel across the balanced transformer.

It is this action which eliminates the lo noise. Noise components which are introduced from the lo are in phase across the crystals and



179.740

Figure 9-26.—Balanced mixer fields.

are therefore cancelled in the balancing transformer. It is necessary that the rf received by the crystals be nearly equal or the lo noise will not completely cancel. It should be noted that only the noise produced by the lo is cancelled. Noise arriving with the echo signal is not affected.

IF Amplifiers

The IF section of a microwave receiver determines the receiver's gain, signal-to-noise ratio, and effective bandwidth. The IF amplifier stages must have sufficient gain and dynamic range to accommodate the expected variation of echo signal power. They must have a low noise figure and a bandpass wide enough to accommodate the range of frequencies associated with the echo pulse.

The most critical stage of a microwave receiver's IF section is the input or first stage. Upon the excellence of this stage, depends the noise figure of the receiver and the performance of the entire receiving system in detecting small objects at long ranges. Not only must gain and bandwidth be considered in the design of the first IF stage, but also, and perhaps of more importance, noise generation in this stage must be low. Noise generated in the input IF stage is amplified by succeeding stages and may exceed the echo signal in strength.

After the first stage, succeeding IF stages may use pentodes to achieve higher gain. This is possible because the signal level has been sufficiently increased by the low noise input stage so as to preclude problems caused by noise generation of pentodes.

The gain of an IF amplifier is high. Because of this high gain, caution must be used to prevent the least amount of regenerative feedback. A small value of voltage in the proper phase fed back to a previous IF stage causes the amplifier to break into oscillations. Because of this, great care is taken to minimize the possibility of positive feedback. Extensive decoupling in the plate and heater circuits of microwave IF amplifiers is necessary and generally provided. Also, IF amplifiers in microwave receivers are usually isolated and well shielded to prevent any undesired feedback or coupling.

The tuning of an IF amplifier section is generally critical. Whenever required, it should be done in accordance with the instructions contained in the manual for the particular equipment concerned, and care should be exercised.

Video Detector and Amplifier

The output of the IF stage (fig. 9-24) is converted to video-frequency signals by the detector stage, which is usually a diode. There is normally a slight loss of amplification in this stage. The video amplifier is used to amplify the detected pulse voltage to the required magnitude necessary to operate the indicator. A cathode follower is used to couple the video signal output to the indicator. A characteristic of a cathode follower is its impedance-matching ability. It is necessary to match the output impedance of the video amplifier to the input admittance of the scope. This tends to minimize the noise, distortions, and attenuations that would normally occur when a coaxial cable is used to feed signals through a remotely located indicator.

Receiver Sensitivity

Increasing the sensitivity of the receiver also increases the maximum range of the radar set. The more sensitive the receiver is, the longer the maximum range at which an echo signal can be detected. The ability of the receiver to detect and amplify a minute quantity of energy is a mark of the quality of the receiver and the factor which determines the maximum range of the radar set.

The method of measuring receiver sensitivity is examined later.

INDICATORS

After the video pulse has been amplified, it must be supplied to the indicator. An indicator produces a visual indication of the echo pulses in a manner designed to furnish the required information content. The parameters desired are range, bearing, and elevation of targets.

As was brought out in the discussion of the synchronizer system, the A trigger (timing) (fig. 9-5) is generated before the mod trigger. The time between the two triggers is used in the indicator system to start the indicator scopes conducting and to allow the time necessary for the indicator sweep voltages to position the display so that it starts at the same spot on the scope for each transmitted pulse, regardless of the radar's prr.

The indicator scopes are normally blanked, that is cut off, except during the range sweep time. Therefore, when the range sweep voltage returns the indication to its start position, the "fly back" of the range line is not seen. The persistency of the scope gives the impression of continuous conduction. The length of the range sweep determines the duration of the unblank voltage to the indicator scopes. Only the video received while the unblank voltage is present is displayed.

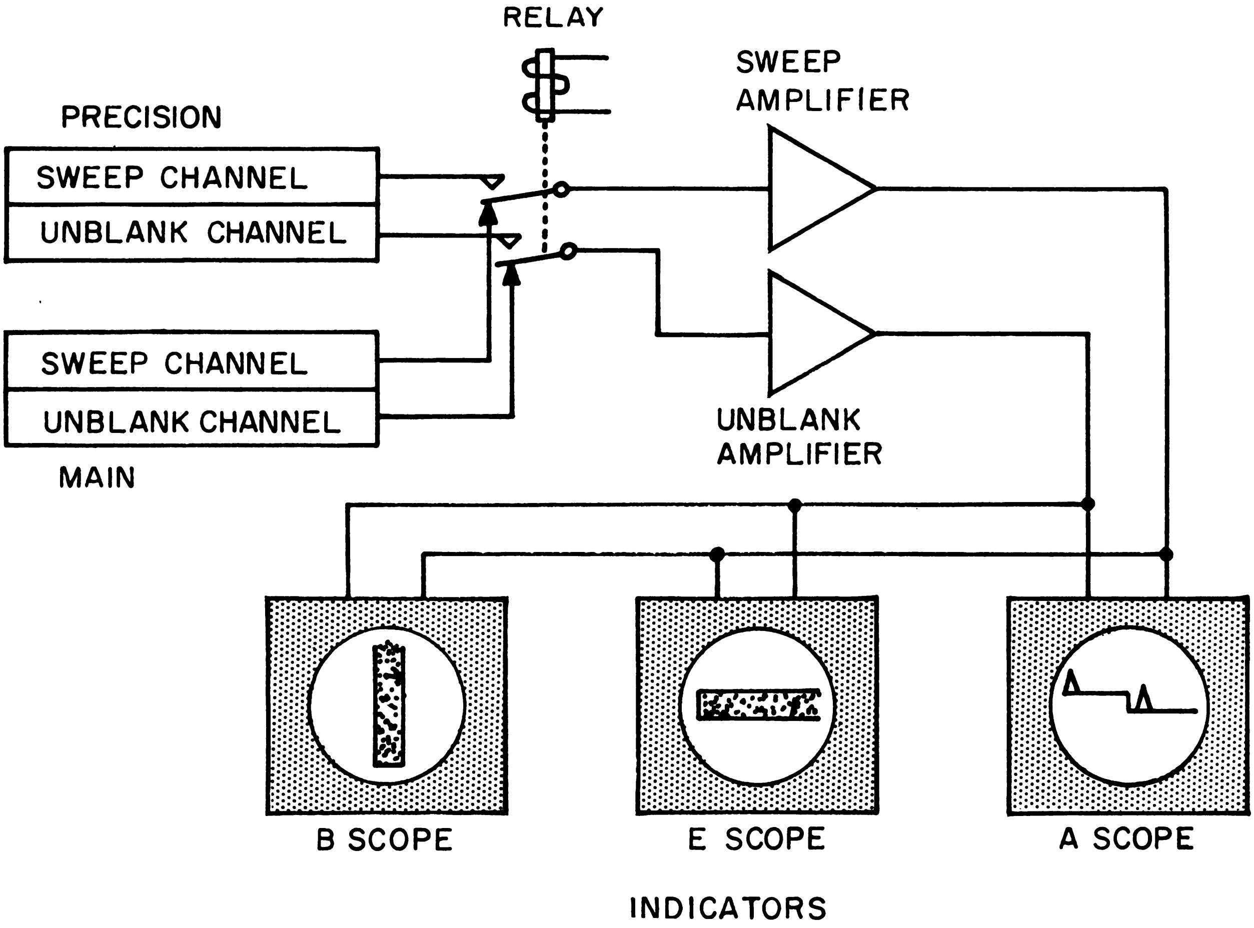
Range Sweep

There are two range sweeps in the radar—Main sweep and PRECISION sweep. When the main or A sweep is used, the indicators display the entire range limits of the radar. The main sweep-voltage generator is triggered by the A trigger from the synchronizer. When the precision of R sweep is used, the indicators show the section of the main sweep about the range of the target. Since the occurrence of the precision sweep is controlled to make it coincide with target range, its sweep-voltage generator is triggered by the movable range pulse from the range system.

Figure 9-27 shows a simplified block diagram of the main and precision range sweep channels. All the indicators have the same range sweep at the same time. Normally the main sweep is used to acquire a target. Once the target is acquired in the beam, the sweep is shifted to precision. The expanded view of a small segment of range in precision sweep enables the operator to measure the target's range more accurately.

Angular Sweep

The B-type and E-type indications show the range to a target plus its position with respect to the boresight axis of the antenna. The radar indicator's presentations were covered earlier. The range line represents the forward-going range sweep across the face of the scope. When the range line passes through the centerline axis of the scope, it is considered to be coincident with the boresight axis of the antenna. The target's angular position is displayed by moving the range line an amount proportional to the



12.319

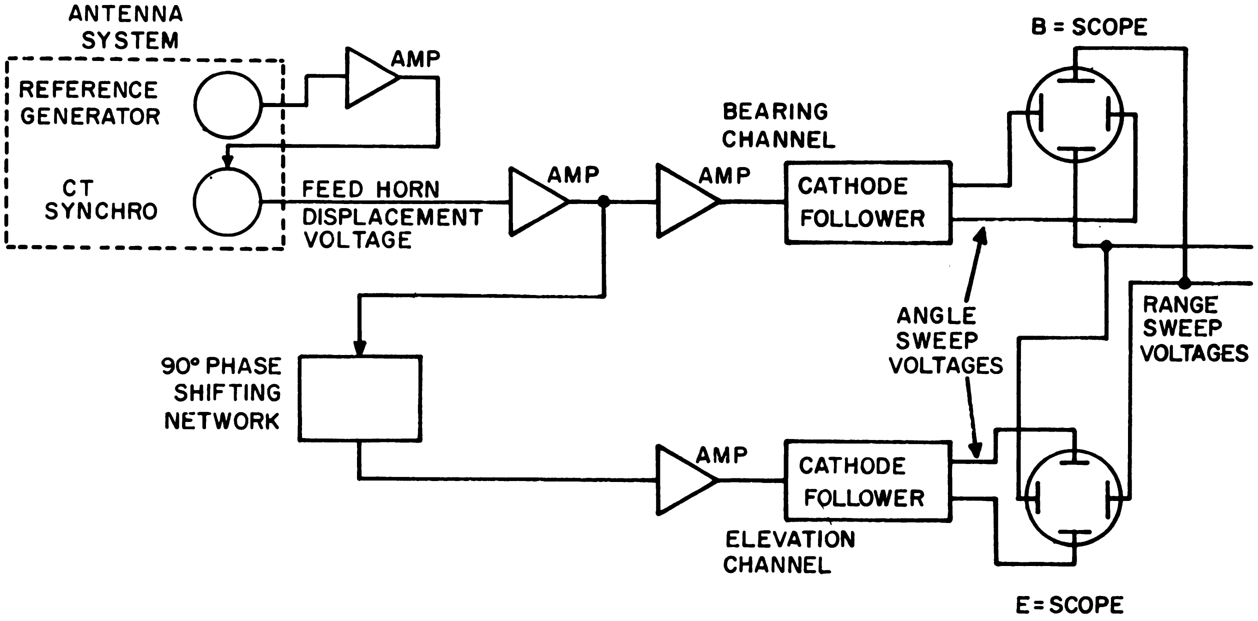
Figure 9-27.—Main and precision channels.

feedhorn offset from the antenna's boresight axis.

A two-phase reference generator provides a reference voltage whose phase indicates the direction of the feedhorn's offset from the nutation axis. The reference voltage from the generator is applied to a control transformer synchro whose output voltage indicates the amount of the feedhorn displacement. This voltage is the input to the angle sweep generator.

In the sweep generator (fig. 9-28), the voltage is amplified and sent to the indicators where it is used to deflect the range line in the B and E scopes so that the line follows the feedhorn in the train or elevation axis as it scans the area about the target. The phase of the voltage is shifted 90° for use in the E scope. The range line is deflected an amount proportional to the position of the feedhorn regardless of the type of scan.

The E-scan presentation (fig. 9-29A). is another type of scan for presenting range and height information. The E scan is also known as the rhi (Range Height Indicator) scan. In the type E scan, an echo appears as a bright spot with range indicated by the horizontal coordinate and elevation (height) by the vertical coordinate. This type of scan is used in Weapon Direction Equipment (WDE) and Weapon

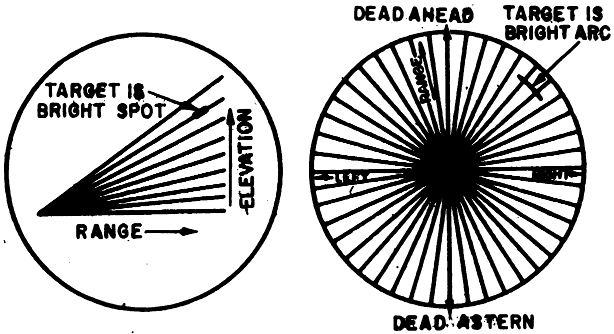


12.320

Figure 9-28.—Angle sweep generator.

Control Stations (WCS). WDE and WCS are discussed in chapter 10.

The ppi (plan position indicator) presentation (fig. 9-29B) is also another type of scan for range and bearing information. It utilizes an intensity-modulated system with a linear-radial sweep for range, and a circular sweep (synchronized with antenna bearing) for target bearing.



A. TYPE E SCAN

B. TYPE P (PPI)

20.281

Figure 9-29.—Radar indicators.

Video Signals

Video signals from the IF amplifier in the receiver are sent to the video amplifier of the indicating system (fig. 9-3). The video amplifier has two channels, the A-video and the B-video channels. The input video signals are applied to both channels. The A-video is used in the A-type presentations. In this type presentation, the video signal appears as a vertical deflection of the A sweep. The range notch signal from the range system is added to the A-video signal and both are sent to the A-type indicators.

The B-video is used in the B and E indicators. These scopes have intensity modulated displays and the video signals appear as bright spots on the scope. The range mark signal from the range system is mixed with the B-video in the amplifier and the signals are sent to the indicators.

Video amplifiers are designed to uniformly amplify a wide band of frequencies, which includes the audio band up to several megahertz. They differ from audio amplifiers only in the values of the circuit components.

RANGE SYSTEM

Once the video signals have been extracted from the returned echos and sent to the indicators, the range to the target must be determined. Range is determined by measuring the time delay between the transmission of the transmitted pulse and the reception of the echo from the target. The time delay is, of course, variable; its length depends on target range. Therefore, the circuits which produce the time delay must be capable of measuring a variable delay. Moreover, the time delay must be measured precisely since range is a very important factor.

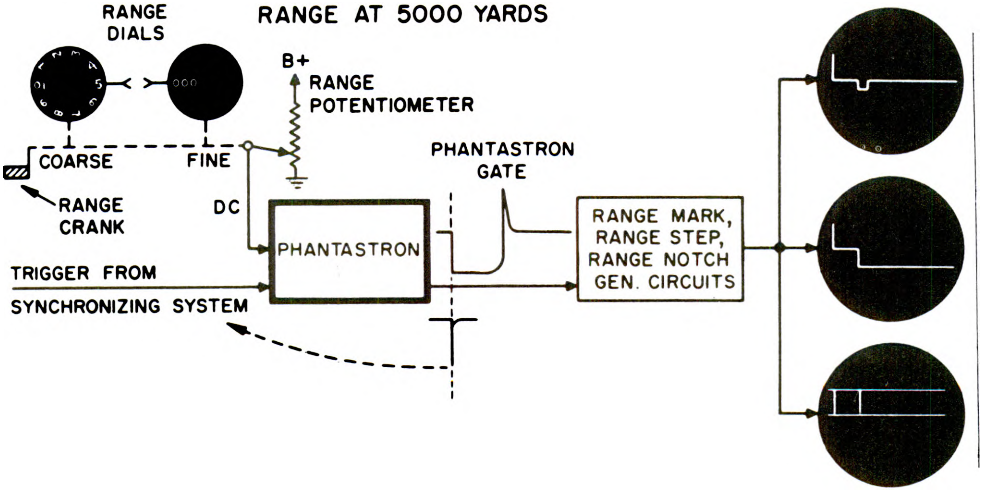
We are again using the terms "time" and "range" interchangeably. There is a linear relationship between time and range in the radar; 6.1 microseconds equals 1,000 yards.

The range system can be divided into a coarse and fine delay circuit. Let's consider the course delay first. To measure the delay, the starting point (zero range), must be established. This is done in the synchronizer system. The A pulse from the synchronizer is used to trigger the coarse delay circuit in the range system.

Coarse Delay Circuit

The coarse delay is measured by a special type of oscillator called a phantastron (fig. 9-30). Plate current in the oscillator tube is cut off before the A-trigger arrives. The A-trigger drives the tube into conduction so that the plate starts to draw current and the plate voltage drops. The output of the tube is a square-wave pulse or gate. The leading edge (left-hand edge) occurs the instant the tube starts to conduct. It, therefore, is fixed in the radar's time system and represents zero in the radar's range system.

As in the blocking oscillator, the shape and duration of the phantastron's output gate is determined by the circuit components and is independent of the input trigger. In this case, one of the components in the circuit is variable. The wiper arm of the range potentiometer shown in the figure moves when the range handcrank is rotated. The voltage from the potentiometer changes the characteristics of the phantastron circuit, which in turn varies the width of its output gate. Thus, the trailing edge (right-hand edge) of the gate is movable and the width of the gate is proportional to the range. The voltage from the potentiometer can vary the



12.316

Figure 9-30.—Range coarse delay circuit.

width of the gate to represent the entire ranging limits of the radar.

The phantastron circuit produces a very linear delay for ranging purposes. The time of occurrence of the trailing edge of the phantastron gate, however, is not sufficiently accurate for fire control ranging. Therefore, the length of the phantastron gate is considered to be the coarse range to the target.

Fine Delay Circuit

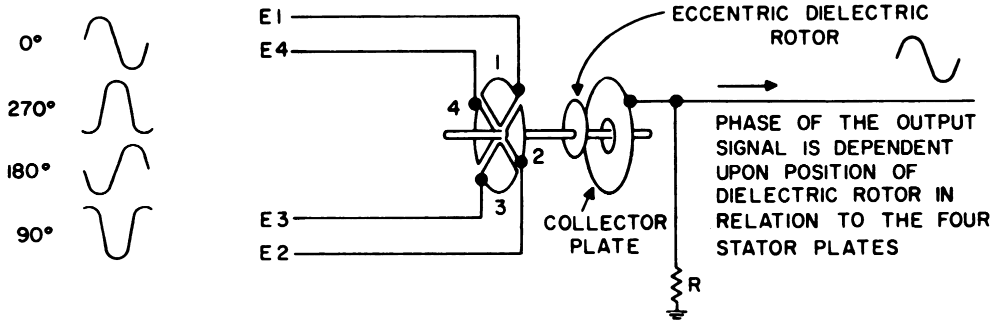
The fine delay circuit produces reference marks, 6.1 microseconds apart, similar to the ones in the synchronizer system, but the range reference marks are movable. The frequency of their occurrence is constant, but the movable marks can be shifted in time from the reference marks in the synchronizer.

The 163.88 kHz oscillator in the synchronizer provides the reference voltage for the fine delay circuit of the range system. The reference voltage is divided into four sine wave voltages in a phase-splitting circuit. (A transformer will shift the phase of a voltage 180°, while an RC circuit can produce a 90° phase shift of a voltage.) The output of the phase-splitting circuit is four sine-wave voltages with a phase relationship of 0°, 90°, 180°, and 270°.

When you studied basic electricity you learned that there is a relationship between the electrical phase of a sine-wave voltage and time. Since the positive peaks of the reference voltage are 6.1 microseconds apart, the positive peaks of the four sine-wave output voltages are separated from one another by about 1.5 microseconds (μs), or 250 yards of range. A range accuracy of 250 yards is not precise enough for fire control purposes. Thus, the time delay as represented by the phase of the reference voltage must be further refined.

The four sine-wave voltages are applied to a specially constructed capacitor, called a variphase capacitor. One of the plates of the capacitor is divided into four insulated segments (fig. 9-31). The voltages are applied, one to each segment of the plate. The dielectric rotor of the capacitor is slightly larger than one of the plate segments and is movable. The rotor is moved by range; one revolution is equal to 1,000 yards of range. The output of the variphase capacitor is a sine-wave voltage whose frequency is 163.88 kHz and whose phase can be varied from the reference voltage through 360°. The phase difference between the reference voltage and the output of the capacitor is equal to a time delay that is proportional to a range of 0 to 1,000 yards. The amount of delay depends upon the range setting in the radar. The output sine-wave voltage is distorted into spikes to produce the fine-delay reference marks.

The time delay, which is proportional to the range set in the radar, is determined by correlating the fine delay with the coarse delay.



0°
270°
180°
90°
E1
E4
E3
E2
1
2
3
4
ECCENTRIC DIELECTRIC ROTOR
COLLECTOR PLATE
PHASE OF THE OUTPUT SIGNAL IS DEPENDENT UPON POSITION OF DIELECTRIC ROTOR IN RELATION TO THE FOUR STATOR PLATES
R

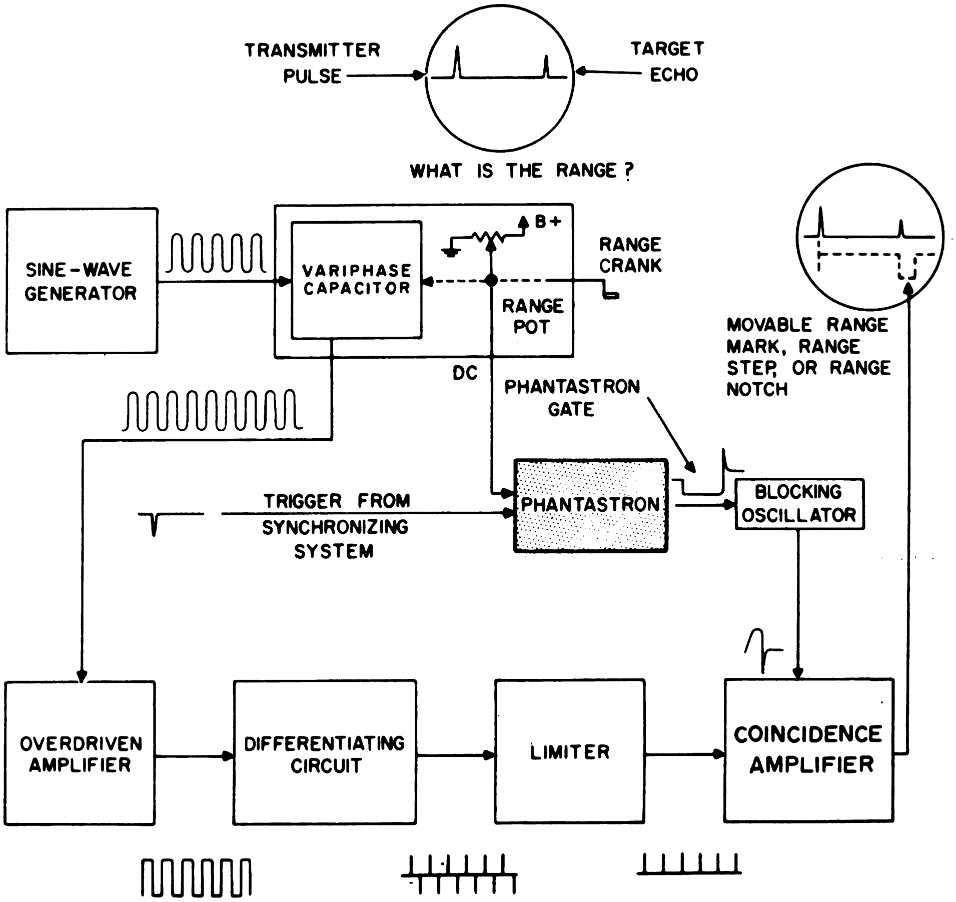
12.317

Figure 9-31.—Variphase capacitor.

The analogy of the minute and hour hands of a clock used in the synchronizer system would serve equally well here to describe the need for the correlation of the two delays.

In figure 9-32 you can see that the phantastron gate is the input to a blocking oscillator. The trailing edge of the gate, which swings sharply positive, triggers the blocking oscillator. The output of the blocking oscillator is an 8-microsecond gating pulse. The gating pulse is the input to the coincidence amplifier. A moveable reference mark is the second input to the coincidence amplifier. When both inputs are present simultaneously, the amplifier has an output. The fine delay plus the coarse delay establishes the exact time delay for the range set into the radar. The output of the coincidence amplifier is amplified and then sent to the indicating system as a range pulse. In the indicating system, the range pulse is used as a trigger to generate a range gate for the tracking system and a range mark, range step, or range notch, depending on the type of presentation of the radar scope.

In the discussion of the range system, the time delay was represented as the range set into the radar and not the target's range. Radar ranging deals with the simultaneous occurrence of the movable range pulse and the target's video pip. When the two are coincident the radar's range is equal to target range. Since both the target's video pip and the range mark or notch



12.318

Figure 9-32.—Range delay circuit.

are displayed in the indicators, it is a simple matter to move the range mark to make them coincident.

AUTOMATIC TRACKING SYSTEM

The tracking system keeps the radar "on target." The radar tracking system works in conjunction with the director power drives and the computer. The interconnections between these equipments was outlined earlier in this course. Therefore, we consider only the radar's tracking system here.

Range Tracking

It is the job of the range tracking system to drive range to keep the target's pip in the range notch. From its job, you can reason that the range tracking system is a servosystem. The first thing the tracking system must do is to determined if the pip is in the notch. If the pip is not in the notch, the tracking system must detect the error and drive the range system so that the pip and the notch occur simultaneously.

A circuit similar to a coincidence amplifier is used to determine if the target's pip is in the notch. A trigger pulse called the range gate is generated at the same time as the range notch. The range gate is one input to the amplifier. The second input is the video signal. When both signals are present in the amplifier, there is an output. An output signifies that the pip is in the notch.

Determining the amount and the direction of a range error is a more difficult job. This is the job of the range error detector. The sensitivity of the error detector is increased by using a balanced network. In one-half of the network, undelayed video signals are applied. When the range is correct, this video signal is coincident with one edge of the range gate. The video signal is also applied to a delay network. It takes the video signal a fraction of a microsecond to pass through the delay network. The delay is approximately equal to the duration of the range gate. The delayed video signal is applied to the other half of the balanced network. When the range is correct, the delayed video occurs at about the same time as the other edge of the range gate.

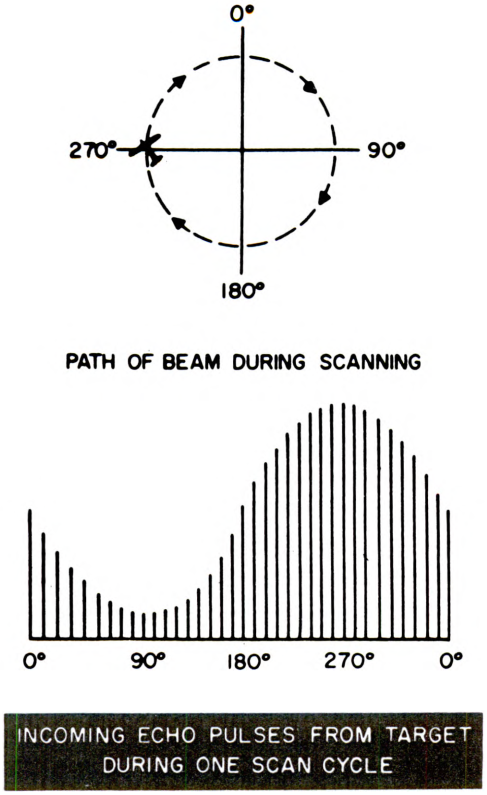
When the range is correct, the equal amount of the undelayed and the delayed video signal is in the gate and the error detector is in balance. If, however, the range were to drift away from the correct value, more of one video signal would be in the gate and less of the other video signal. The error detector would be out of balance and would send an error signal to the range servosystem. The polarity of the error signal indicates the direction of error. This is determined by comparing the strength of the video signals in the gate.

The video signals in the range gate are used to select the target for the tracking system. When the video signal and the range gate occur simultaneously, an output from the range tracking system is used to start the automatic gain control (agc) in the receiver and to start automatic tracking in the train and elevation of the gated signal.

Train and Elevation Tracking

The radar's angle error-detecting circuits provide correction signals to the director power drives. The correction signals are proportional to the target's displacement from the nutation axis of the antenna. Target displacement is detected by comparing the video signals from subsequent pulses. Let us look at a series of video signals from a target to see how the error signal is detected. Assume the radar is in conical scan and locked on the target. Place the target in the left-hand portion of the beam coverage of the radar (fig. 9-33) to produce an error in train. Normally, in automatic tracking a target would not be this far off of beam center.

When the center of the beam (fig. 9-33), is at 0°, the video return from the target is relatively small. As the center of the beam rotates in a clockwise direction, each successive video signal becomes smaller until, at 90°, a minimum video signal is received. As the beam center continues to move, the amplitude of the video signals increases until a maximum signal is received when the beam center is on target at 270°.



PATH OF BEAM DURING SCANNING

INCOMING ECHO PULSES FROM TARGET DURING ONE SCAN CYCLE

12.321

Figure 9-33.—Amplitude and phase modulation of the video signal.

Further clockwise rotation moves the beam center away from the target and the video reduces in amplitude.

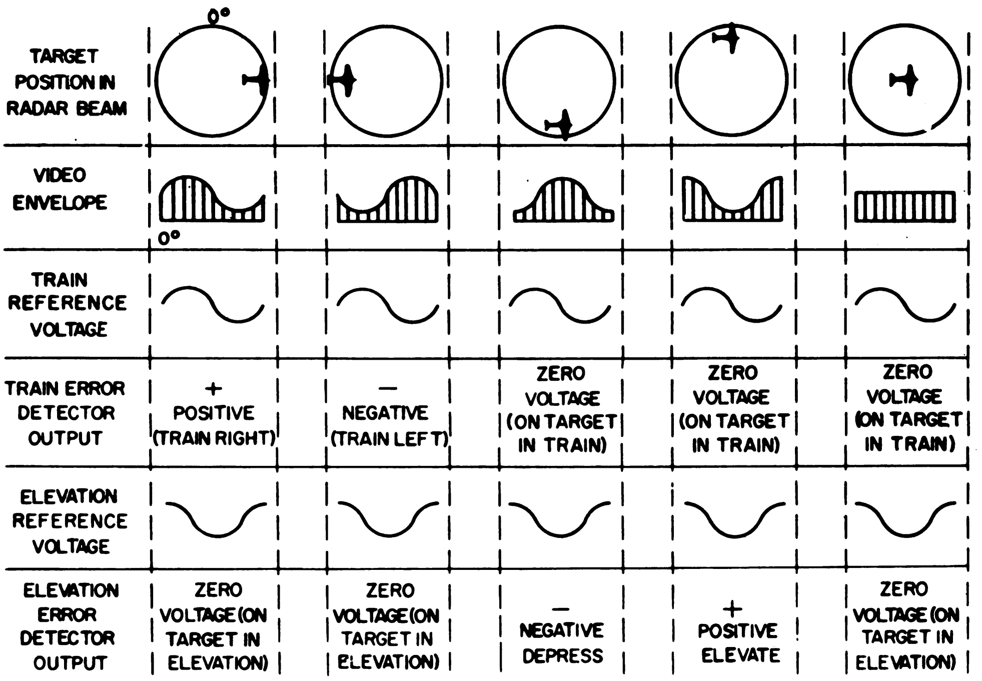
Notice in figure 9-33 that the video signal for a complete nutation of the feedhorn forms a sine wave. The sine wave is called the video envelope. The frequency of the video envelope is the same as the scan rate of the radar. The phase of the envelope is established by the position of the target relative to the center of the beam coverage of the radar. If the target had been to the right of the center of the coverage of the radar beam, the phase of the envelope in the figure would have been inverted. The amplitude modulation of the video signals established the amount of target displacement from the center of the beam coverage of the radar. If the target had been in the center of the beam coverage, the video signals would all have been of the same amplitude.

The two-phase reference generator in the antenna (fig. 9-28) established the position of the feedhorn relative to the nutation axis of the antenna. The generator provides the reference voltages for the train and elevation error-detector circuits. The elevation reference voltage is 90° out of phase with the train reference voltage. Each error detector circuit compares the phase of its reference voltage with the phase of its video envelope. The phase comparison (fig. 9-34), indicates the direction of the error. The amplitude modulation of the video envelope is compared to the amplitude of the reference voltage to determine the amount of error.

RADAR COUNTERMEASURES

A target can defeat a radar system in a variety of ways. Any countermeasures which give false target information, such as chaff, can be effective, since they tend to obscure exact target position and may overload the radar with false targets. In these instances, the most effective countermeasure is a highly trained operator or an accurate discerning mechanism capable of distinguishing false targets from real ones.

Jamming techniques are similarly effective because exact target position is lost in the jamming signal. Delay circuits, homing devices, and randomness of output are all effective methods of countering jamming techniques. Targets capable of carrying even more complex equipment than that required for jamming may actually transmit false positional information that may be picked up and interpreted as energy reflections by the radar attempting to locate it. This method is particularly effective against radar systems relying on a doppler frequency shift. Since this countermeasure involves not only recognizing a signal, but also computing and transmitting another signal, it cannot yet be accomplished instantaneously. Therefore, coded or random pulse trains are effective counter-countermeasures at present.


0°
TARGET POSITION IN RADAR BEAM
VIDEO ENVELOPE
0°
TRAIN REFERENCE VOLTAGE
TRAIN ERROR DETECTOR OUTPUT
+ POSITIVE (TRAIN RIGHT)
— NEGATIVE (TRAIN LEFT)
ZERO VOLTAGE (ON TARGET IN TRAIN)
ZERO VOLTAGE (ON TARGET IN TRAIN)
ZERO VOLTAGE (ON TARGET IN TRAIN)
ELEVATION REFERENCE VOLTAGE
ELEVATION ERROR DETECTOR OUTPUT
ZERO VOLTAGE (ON TARGET IN ELEVATION)
ZERO VOLTAGE (ON TARGET IN ELEVATION)
— NEGATIVE DEPRESS
+ POSITIVE ELEVATE
ZERO VOLTAGE (ON TARGET IN ELEVATION)

12.332

Figure 9-34.—Phase comparison.

Spoofing or electronically simulating targets is also employed to overload and fool radar systems. Again, coding or randomness of outputs can successfully defeat this form of countermeasure.

It is essential that a radar be flexible enough to handle all of the countermeasures it can expect. It is also imperative that the radar recognize false targets in their initial stages. Once it begins tracking them, their purpose has been accomplished and when there are enough of them the radar will overload and break down. A breakdown does not mean that the radar actually ceases to function, but, rather, that it is no longer furnishing an appreciable portion of the target information needed.

Splits and merges are conditions inherent in the multiple target problem and add to tracking difficulties. Splits occur when a contact detected by the radar as a single target splits into two or more discernable targets. Merges occur when several targets come together so that they appear as one target to the radar. The ability to pick out and ignore false targets is, therefore, of prime important in handling multiple target situations.

There are many variations of countermeasures in existance and also numerous new possibilities; therefore, as can be seen from the previous discussion, enemy jamming can offer a radar operator a real challenge. You must not, however, feel that jamming is so intense and effective that nothing can be done about it.

Remember that, during jamming, you are not expected to have all of the target information all of the time, as when in normal operation. With modern weapon systems, a kill can be obtained even with only partial target information.

Recognizing and identifying radar countermeasures is over half the battle. If you have succeeded in accomplishing this, you have eliminated the elements of confusion and surprise which the enemy has tried to force on you. You are then able to cope more efficiently with the countermeasures being applied, and you should be able again to gain useful information from your fire control radar.

RADAR MAINTENANCE

It is possible, to some degree, to determine the satisfactory operation of a radar by observing its operation. However, reliance cannot be placed solely on operation to judge the performance of a radar against its designed capabilities. For example, a radar with a ranging capability of 50,000 yards may be able to pick up and track targets out to 40,000 yards. As long as the target does not exceed 40,000 yards of range, the radar would appear to be operating efficiently. But actually, the radar has lost 20 percent of its operating efficiency. Numerous tests must be made in a systematic maintenance program to verify that the radar is operating at its peak efficiency. Radar testing in the broad sense, includes some adjustments and troubleshooting and requires technical skill and know-how.

Testing is a comparison technique that evaluates the quantity being tested against a known criterion. Hence a test by its very nature involves some form of measurement. Radar tests deal mainly with the basic electrical quantities of voltage, current, resistance, capacitance, inductance, and impedance. In addition, measurements are made of power, frequency, waveforms, modulation of the carrier, standing waves in the transmission lines, field intensity of the radar beam, and noise in the radar receiver. Moreover, fire control radar is part of a system, and its function as part of the system must be tested.

BUILT-IN TEST DEVICES

Radars have built-in meters to measure voltages and currents in their critical circuits. Where a voltage with an extremely high amplitude or frequency is present, as in the crystal mixers, if it is possible, a current reading is used to indicate the circuit's operation. Conventional meters can be used as long as we are not dealing with rf or IF circuits. Therefore, what we are concerned with here are meters and devices designed to operate with the high frequencies used in radars.

Directional Coupler

A directional coupler, as the name implies, couples or samples energy from a wave traveling in one direction in a waveguide. Directional couplers are stable, accurate, broadband coupling devices. In most cases, they are built into the radar and are connected so as to sample the transmitted rf signal. But, as you will see, they can be connected to measure either the incident or the reflected waves.

Figure 9-35 shows a common type of directional coupler. It consists of a short section of waveguide with a matched load in one end and a coaxial output probe in the other end. It is coupled to the main waveguide by two holes. The degree of coupling between the waveguide and the coupler is determined by the size of the two holes.

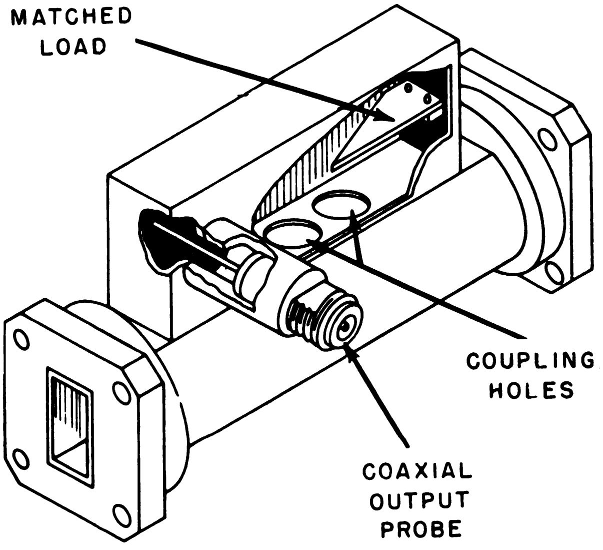


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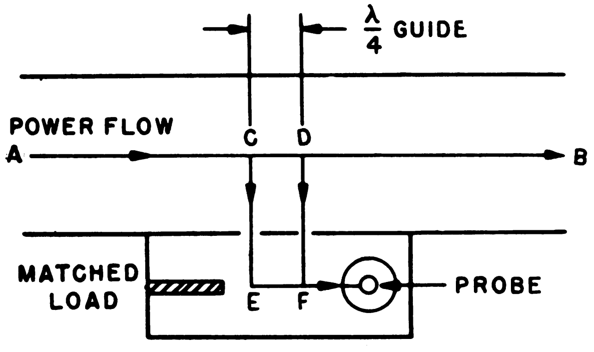
Figure 9-35.—Directional coupler, cutaway view.



166.106
Figure 9-36.—Directional coupler, direct power flow.

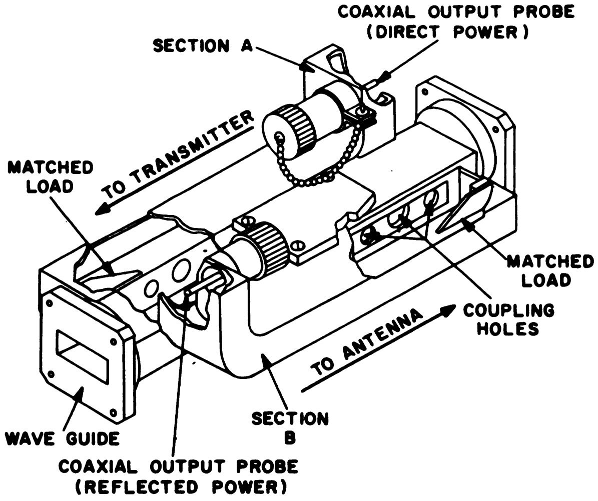
Operation of the coupler is explained by the diagram in figure 9-36. Radio frequency energy is flowing in the waveguide from A to B, and two small samples are coupled out at points C and D. The two paths, C-D-F and C-E-F, to the coaxial probe are the same length. Hence, the two samples arrive in a phase and are picked up by the output probe. There is a one-half wavelength difference in the paths to the matched load, C-D-F-E and C-E, however, because the two holes are one-quarter wavelength apart. Therefore, the two samples arrive 180° out of phase at point E and cancel each other. Now assume that a reflected wave is traveling in the opposite direction in the main waveguide, that is, from B to A. The paths of the samples in the coupler would be reversed. The length of paths D-F-E and D-C-E would be equal, and the samples would arrive at the matched load in phase. The sample energy would be dissipated by the load. But the length of path D-C-E-F would be one-half wavelength longer than path D-F and the samples, which are 180° out of phase, would cancel. Therefore, the samples from a wave traveling in the opposite direction would not affect the output probe of the coupler. The result is that the coaxial probe receives power only from a wave traveling from A to B in the main waveguide, and any reflections causing power to flow from B to A have no effect on the signal measured by the coupler. Of course, if the coupler were turned around, it would measure the reflected power and not the transmitted power.

A directional coupler is frequency sensitive, since both forward attenuation and directivity are determined by the relationship between wavelength and the distance separating the coupling holes. The frequency sensitivity of a directional coupler can be reduced by using three coupling holes. The holes are placed one-quarter wavelength apart. The center hole is larger and couples twice as much power as either end hole. It serves as a common coupling to end holes. As a result, the three-hole coupler has the action of two directional couplers, and is a broadband coupler.

A bidirectional coupler (fig. 9-37), is composed of two three-hole directional couplers combined so that power flowing in either direction in the waveguide can be measured. As you can see, the output probes are located at the opposite ends of the coupler. Therefore, section A of the coupler measures the power flowing toward the antenna or the transmitted power, while section B measures power reflected from the antenna in the waveguide or energy received from a target.

Bolometer

A bolometer is a specially constructed device of temperature-sensitive material used to measure rf energy. The electrical resistance of



70.32
Figure 9-37.—Bidirectional coupler.

the active material changes when it is heated by the radar's rf energy. Two types of bolometers are commonly used in fire control radars. One type is called the barretter. Its active material is a short length of special resistance wire, which has a positive temperature coefficient of resistance. (This means that an increase in temperature causes an increase in its electrical resistance.) The second type of bolometer is called a thermistor. Its active material is a small bead of semiconductor material, which has a negative temperature coefficient of resistance. (This means that an increase in temperature causes a decrease in electrical resistance.)

The bolometer is positioned in the radar waveguide so that the rf energy will be applied to the active material. When the rf energy is applied, the power absorption heats the material and causes a change in its resistance. Thus, a bolometer can be used in a bridge circuit so that small resistance changes can be easily detected and power readings obtained by measuring the condition of balance in the bridge circuit. Basically, there are two methods used to measure the balance status of a bridge circuit. In the first method, the bridge is initially balanced by a bias voltage. Then, the rf energy is applied to the bolometer; the bias voltage is changed until the bridge is again in balance. The change in the bias voltage is proportional to the rf power applied to the bolometer. In the second method, the bridge circuit is not rebalanced. The indication of the unbalanced condition is converted to an rf power reading. In other words, there is a condition of balance when no rf power is applied, and when rf power is applied there is a condition of unbalance owing to the bolometer resistance change. It is this change of resistance that can be calibrated into rf power units.

Figure 9-38A shows a bolometer connected to a radar in a simplified block diagram. The coupling device is connected to the waveguide to obtain a sample of the rf energy. The calibrated attenuator reduces the amount of rf power applied to the bolometer by a known percentage. A bolometer is a low-power device and would be destroyed if exposed to the full power of the radar. The accuracy of the power reading is not affected since the percentage of attenuation is known and is compensated for in the final reading.

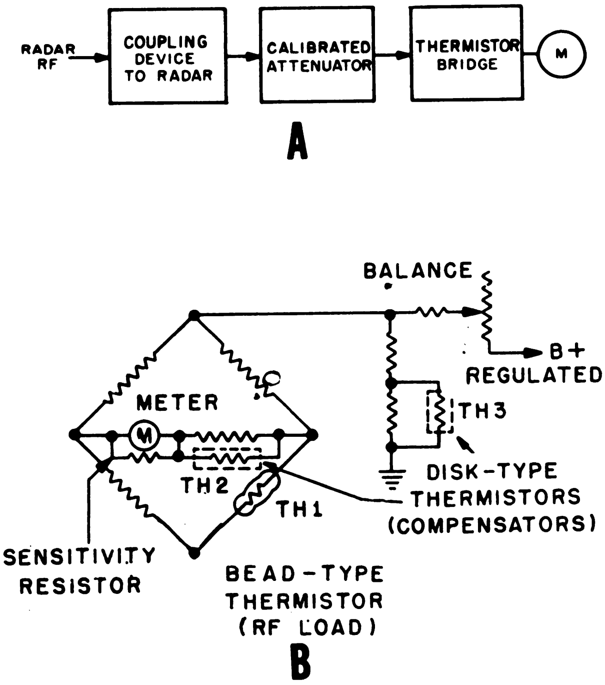


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Figure 9-38.—Thermistor rf power measurement: A. Block diagram; B. Compensated bridge circuit.

Figure 9-38B shows a thermistor bridge circuit. The rf power is applied only to thermistor TH1. The other two thermistors, TH2 and TH3, compensate for temperature variations about the bolometer mounting. Temperature compensation is necessary to maintain bridge balance and to keep the sensitivity of the circuit under constant varying temperature conditions. When the temperature rises, the resistance of bead thermistor TH1 drops and causes an imbalance in the bridge circuit. However, the resistance of TH3, which along with its associated resistors is in parallel with the bridge circuit, also drops, causing a reduction in the d.c. voltage applied to the bridge. The reduced d.c. power increases the resistance of TH1 and returns the bridge back into balance. But, the lower d.c. power reduces the sensitivity of the bridge circuit. Thermistor TH2 is, effectively, in series with the meter. At high temperatures, where bridge sensitivity is reduced, TH2 presents a lower series resistance to the meter. This increases the sensitivity of the meter circuit in the same proportion as the loss of bridge sensitivity. Thus, the overall sensitivity is maintained essentially constant at different temperatures.

A bolometer measures the average power level rather than the peak power of a radar. The resistance of a thermistor changes as the bead heats or cools. The amount of time required for an appreciable change in resistance is large compared to the pulse period of a radar. The thermal time lag includes many radar pulses, with the result that average power is read.

Dummy Antenna Or Load

A dummy antenna or load is used to dissipate excess power or to serve as a terminating load for the radar transmitter. The dummy load is a nonreactive portion of the

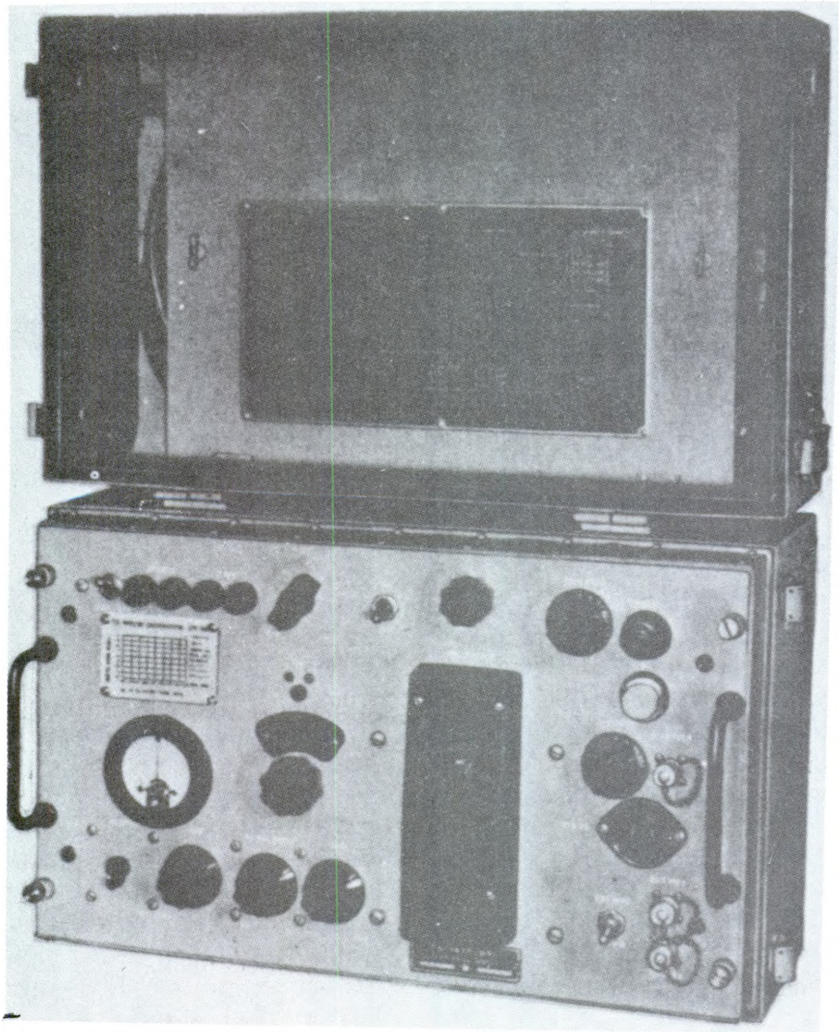

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Figure 9-39.—TS-147.

transmission line, which absorbs power without causing reflected waves in the line. A dummy load can be used to determine the cause of a high standing wave ratio along the transmission line. It also provides a means to operate the radar for testing in an area where military security prohibits any rf radiation.

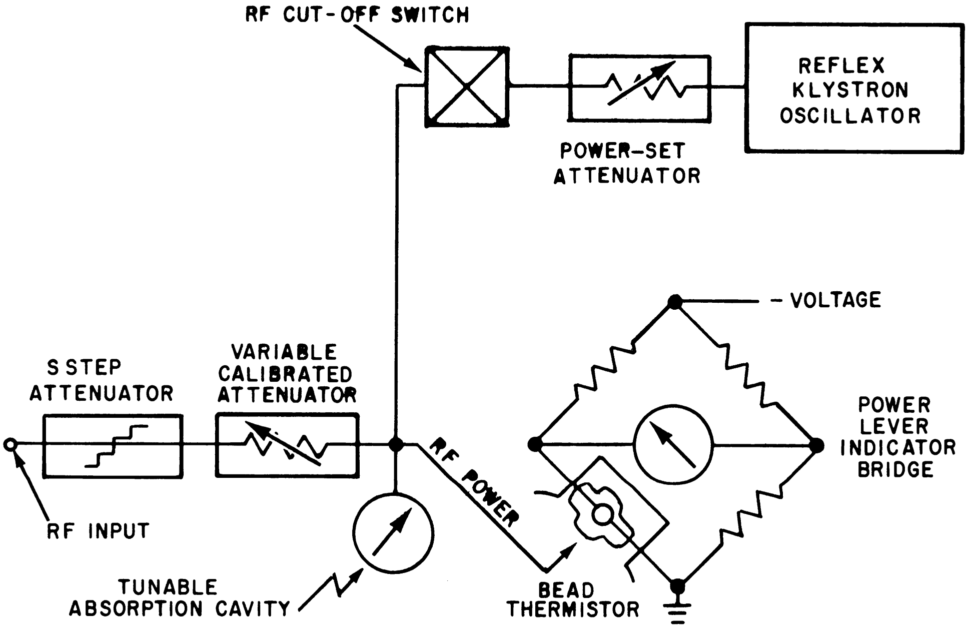
RADAR TEST SETS

Our discussion of radar test sets covers those commonly used to test fire control radars. We are interested in the principles involved in testing the radar and not in the specific details of the design of the test set. The details of a test set are covered in its technical manual.

The TS-147

The TS-147 (fig. 9-39) is a portable test instrument designed to operate in the microwave region. It is a combination of several test equipments in one unit. It contains a power meter, a frequency meter, and an rf signal generator (fig. 9-40). The rf input signal passes through a step attenuator and a variable calibrated attenuator, and by a tunable cavity on its way to the power-level indicator bridge. The reflex klystron is used as an rf generator. The klystron oscillator may be cut out of the circuit by the rf cutoff switch.

The operation of the power level bridge is described, since it is used to determine the frequency and to measure power. When the resistors in the outer legs of a bridge circuit are equal, no current flows in the center leg. Hence, the meter in the center leg indicates whether or not the bridge is balanced. The resistor in one of the legs is a bead thermistor. It is mounted in a waveguide section so that it absorbs the rf energy in which we are interested. The rf energy causes the thermistor to heat up, which decreases its resistance and so unbalances the bridge circuit. With the bridge circuit unbalanced, current flow through the meter is proportional to the degree of imbalance. The meter is calibrated to indirectly indicate the amount of rf energy dissipated by heating the thermistor. When one milliwatt of power is being absorbed by the thermistor, the meter reads SET POWER.


RF CUT-OFF SWITCH
POWER-SET ATTENUATOR
REFLEX KLYSTRON OSCILLATOR
- VOLTAGE
S STEP ATTENUATOR
VARIABLE CALIBRATED ATTENUATOR
POWER LEVER INDICATOR BRIDGE
RF POWER
RF INPUT
TUNABLE ABSORPTION CAVITY
BEAD THERMISTOR

166.110

Figure 9-40.—Simplified block diagram of the TS-147.

Now let us see how we can use the TS-147 to measure the rf power in a radar's waveguide. The rf input to the test set is taken from a directional coupler in the radar. The rf input power is attenuated by the step attenuator and by the variable calibrated attenuator. The reduced rf power is then applied to the bead thermistor in the bridge circuit. The calibrated attenuator is adjusted until the bridge meter reads set power. At this time we know exactly 1 milliwatt of input power is being absorbed by the thermistor and the remaining rf power is being absorbed by the attenuators. Therefore, when we add the step attenuator dial reading to the calibrator dial reading we obtain the total attenuation, which is the reciprocal of the applied rf power. (The 1 milliwatt of power used by the thermistor is included in the dial readings.)

The dials of the attenuators are graduated in dbm, which is the abbreviation for decibels above 1 milliwatt. In this system of measure, 10 dbm is equal to 10 milliwatts, while 20 dbm is equal to 100 or 10^2 milliwatts. Carrying this a bit further, 30 dbm is 10^3 milliwatts or 1 watt, and 90 dbm is 10^9 milliwatts or 1 megawatt. Conversion from dbm notation to actual power readings is usually done by using a chart, but it can be done with pencil and paper.

Frequency measurements with the test set are obtained in almost the same manner as power measurements, except for the use of the absorption cavity, the absorption cavity is a resonant cavity that absorbs energy from the waveguide when it is tuned to the frequency of the energy in the guide. First, the rf power is determined, as described earlier. Then, the frequency of the cavity is varied until it starts to absorb energy from the waveguide. This is indicated by a dip in the power level meter. The closer to resonance the cavity is tuned, the more energy it absorbs and the further the meter dips. When the meter dip is maximum, the dial attached to the absorption cavity indicates the frequency of the rf energy in the waveguide.

The use of the TS-147 for frequency measurements should point out one item about measuring power. When power is measured, the absorption cavity must be detuned to prevent it from absorbing a portion of the power and thus causing a false power reading.

When the TS-147 is used as an rf signal generator, the klystron oscillator produces oscillations at the proper frequency. The power bridge and the frequency meter are used to determine this frequency. The power output is adjusted to 1 milliwatt by the power-set attenuator. The test set is generating a signal with a known frequency and a known power level. This output can be used to tune the radar receiver.

Spectrum Analyzer

A spectrum analyzer (fig. 9-41) provides a visual indication of the radio frequencies present within an rf pulse. You may be wondering why we should be interested in the frequency spectrum of an rf pulse. The spectrum of a transmitter is compared with the response curve of a receiver in figure 9-42. The receiver's response curve has a broader bandwidth than the transmitted frequency to ensure complete coverage. But the receiver responds best to frequencies in the middle of its bandwidth. Its response tapers off on both sides of the center frequency until it passes through the half-power points on the curve. Usually the response beyond these points is not considered. As you can see, the spectrum of the transmitter is centered in the receiver's response curve, thus yielding maximum efficiency. While it is impossible to transmit all the power on one frequency, it is desirable to have most of the power near that frequency. Any portion of the spectrum that falls near the edge of the response curve or outside the bandwidth of the receiver is wasted. This is why you will use a spectrum analyzer to determine whether or not the transmitter is producing the proper frequency for maximum efficiency.

Before we discuss the test set, let us define and discuss a spectrum generated by a radar transmitter. The output of a radar oscillator does not consist of a fundamental frequency that is turned on and off at the pulse-repetition frequency (prf), but must be considered as a

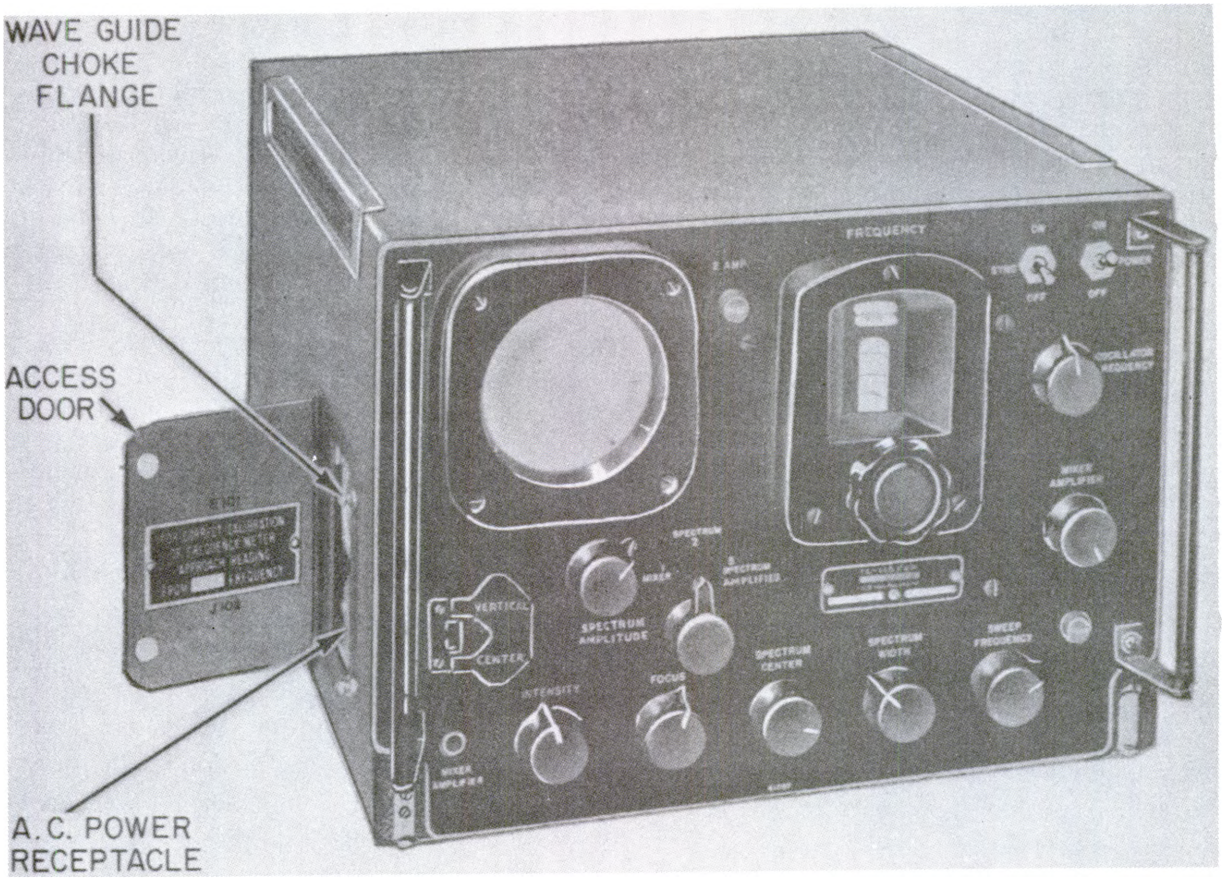


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Figure 9-41.—Spectrum analyzer.

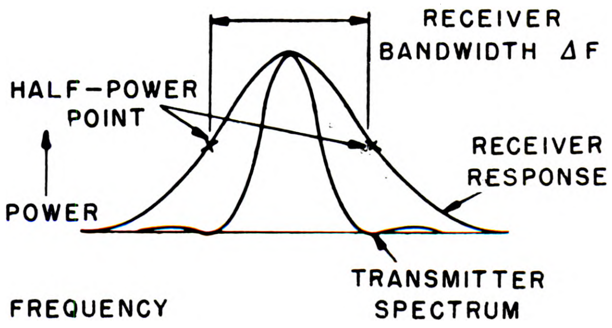

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Figure 9-42.—A transmitter spectrum compared with a receiver response.

fundamental frequency or carrier that is modulated by short rectangular pulses occurring at the prf of the radar. Thus, there are two distinct modulating components present. One component consists of the prf and its associated harmonics, and the other component consists of the fundamental and odd-harmonic frequencies that comprise the rectangular pulse. (A square wave can be considered to consist of a fundamental sine wave plus an infinite number of odd-harmonic, in-phase sine waves.)

Any frequency when modulated by another frequency produces a fundamental frequency with sideband frequencies. In other words, a radar output appears on more than one frequency. The distribution of power over this frequency depends on the amount of modulation. The plot of the power versus the frequency is called the radar spectrum (fig. 9-43). The vertical lines represent the modulation frequencies produced by the prf and its associated harmonics, while the lobes represent the modulation frequencies produced by the fundamental pulse frequency and its associated harmonics. The amplitude of the main lobe falls on either side of the carrier, until it is zero at the point corresponding. The side lobes are produced by the odd harmonics of the fundamental pulse frequency, while the zero points are produced by the even-harmonics of the fundamental pulse frequency. In an ideal spectrum, each frequency above the carrier has its counterpart in another frequency equally placed and with equal power below the carrier, so that the pattern is symmetrical about the carrier. The main lobe, of course, contains the major portion of the transmitted energy.

Figure 9-44 is a simplified block diagram of a spectrum analyzer. The rf input is a sample of the radar's transmitted energy that contains the pulses to be analyzed. The variable attenuator adjusts the amplitude of the sample pulses applied to the crystal mixer. In the mixer, the attenuated pulses are combined with the varying output of the local oscillator. The local oscillator is a reflex klystron that is caused to sweep across its frequency band by a sawtooth waveform generated in the variable sweep generator. The sawtooth waveform is also applied to the sweep circuit of the oscilloscope. Hence, there is a relationship between the frequency output of the local oscillator and the sweep across the face of the crt indicator.

The output of the crystal mixer is the combination of the attenuated rf input pulses and the signal from the local oscillator, which is varying across the frequency band of the klystron. Since the IF amplifier is tuned to a very narrow band of frequencies, the only time it has an output is when the varying local-oscillator frequency mixes with one of the frequencies present in the rf pulse to produce the correct IF. This means that the presentation on the crt looks something like that shown in figure 9-43. The power output of the local oscillator can be assumed to be constant; therefore, the vertical deflection of the spectrum on the scope is proportional to the power

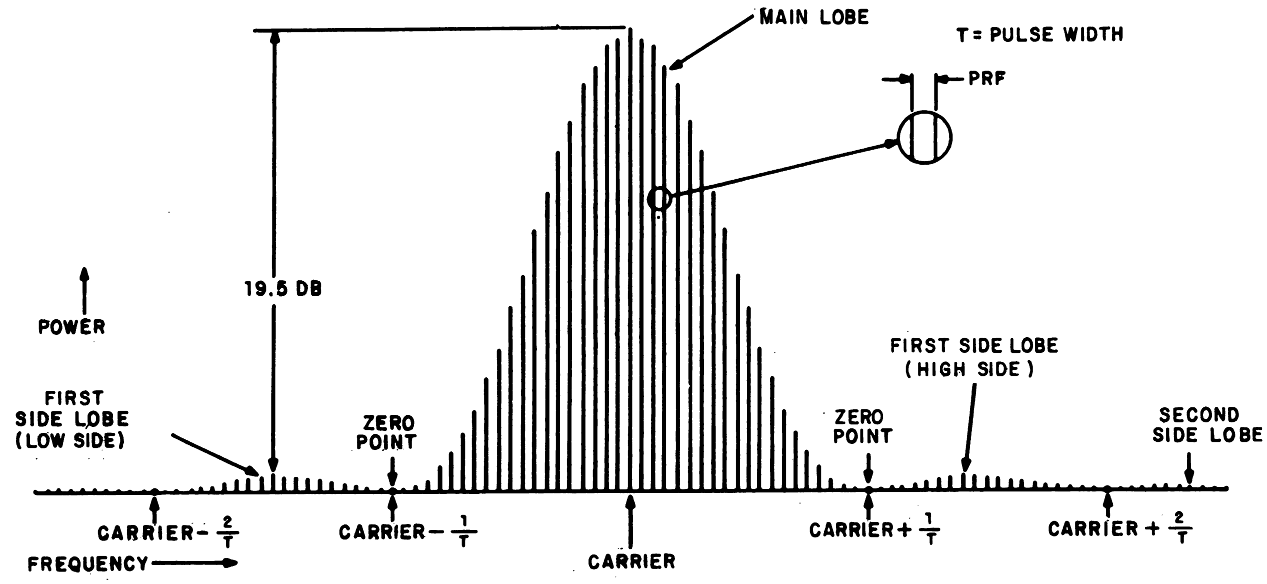

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Figure 9-43.—Ideal spectral display of a pulse-modulated rf carrier.

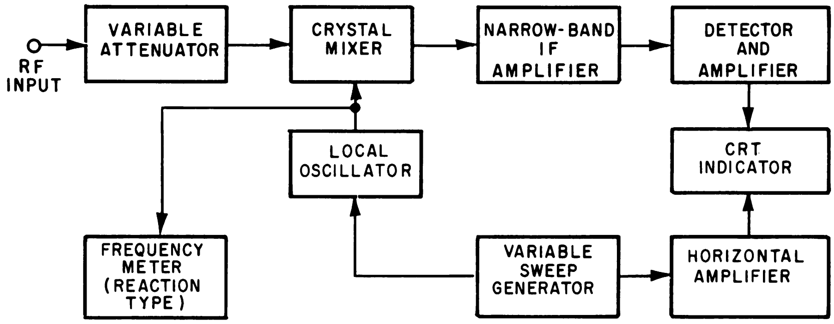

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Figure 9-44.—Simplified block diagram of a spectrum analyzer.

present in the rf pulse at that particular frequency.

The location on the scope is determined by the sawtooth sweep voltage, which causes the local oscillator to be swept through the rf frequency. It is possible to adjust the crt display so that two separate spectrums are seen. This happens because the mixer produces the proper IF signal whether the local oscillator is tuned above or below the rf signal. The separate spectrums can be used to determine the frequency of the rf input. When the local-oscillator output passes through the frequency to which the frequency meter is tuned, a pip is produced on the crt at a position denoting that frequency. Figure 9-45 shows the twin spectrums and the frequency meter pip. The spectrum on the left occurs when the local oscillator is below the rf, and that on the right occurs when the local oscillator is above the rf. The frequency meter pip is placed exactly in the center, as shown. The instant the pip is in the center, both spectrums decrease in amplitude and the rf frequency can be read from the frequency meter dial. There are other methods of determining the frequency, but those along with the use of a spectrum analyzer in corrective maintenance, are covered in a later manual.

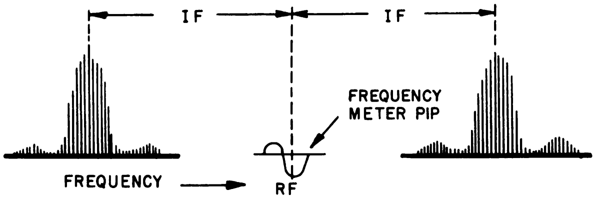

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Figure 9-45.—Twin spectrum and frequency meter pip.

RADAR COLLIMATION

Radar collimation provides for the parallel alignment of the radar beam axis and optical axis of the radar antenna. This can be accomplished by the use of a shore tower on which is located an optical target and a radar horn antenna (fig. 9-46). The horn antenna is connected to rf power measuring equipment and is properly positioned in relation to the optical target. The horn antenna displacement, relative to the optical target, would be determined by the relative displacement of the two axes (optical and rf) as measured at the radar.

To check or adjust for parallelism of the two axes, the radar antenna is trained and elevated until the cross hairs of the optical sight intersect the optical target. At this time, maximum rf energy should be directed into the horn antenna as measured by the power measuring equipment. If not, the axes are not collimated and appropriate adjustment procedures should be accomplished. In brief, this requires that one axis be aligned to the other until they are

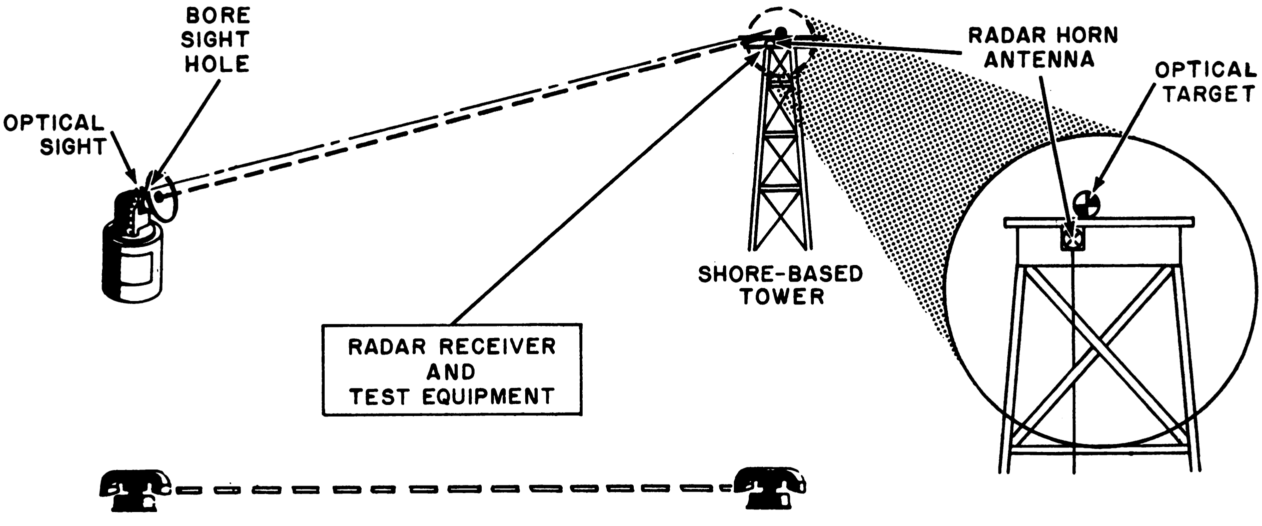

Figure 9-46.—Radar collimation.

parallel. Step-by-step procedures for accomplishing this alignment varies between radar installations. You should refer to applicable radar equipment documentation for information of this nature.

Collimation of the tracking/acquisition rf axes of a radar to its director (optical axis) is necessary to ensure (1) accurate definition of target position by the director to the fire control computer, and (2) adequate illumination of the target by the continuous-wave illuminating beam. The measurements that must be made in order to determine if the radar is collimated to the director require use of a shore tower (fig. 9-46). Other measurements and alignments requiring the shore tower are measurement of the angle error sensitivity, measurement of the angular position of the track-transmit axis with respect to the receive axis, and alignment of television cameras.

Collimation requires the use of antenna and optical array which is mounted on the shore tower. Antenna-optical arrays are also mounted aboard ship to provide a means of accomplishing collimation when shore towers are not available. The procedures are basically the same as those involving shore towers. Allowance, however, does have to be made for the shorter distances that prevail aboard ship.

CHAPTER 10

WEAPONS DIRECTION AND DESIGNATION EQUIPMENT

INTRODUCTION

As stated in chapter 9 on fire control radar, the radar's rf energy is focused into a pencil beam. This is great for the accuracy of the radar, but is not so good when the radar is searching for a target. The narrow beam could be a few degrees away from a target, and the radar would never detect it. Weapons direction or designation equipment (fig. 10-1) direct (or steer) a fire control radar to a selected target so that it may acquire and track it. Also, with the advent of high-speed aircraft, ships, and missiles, the rapid handling and evaluation of target data—from detection to destruction—has gained importance. This has caused the introduction of a systems concept that goes beyond the traditional fire control system.

Traditionally, the equipment used to control a particular gun or missile battery was known as a fire control system. The introduction of instruments and entire systems that do not fall directly into this category gave rise to the term Weapons Control System (WCS).

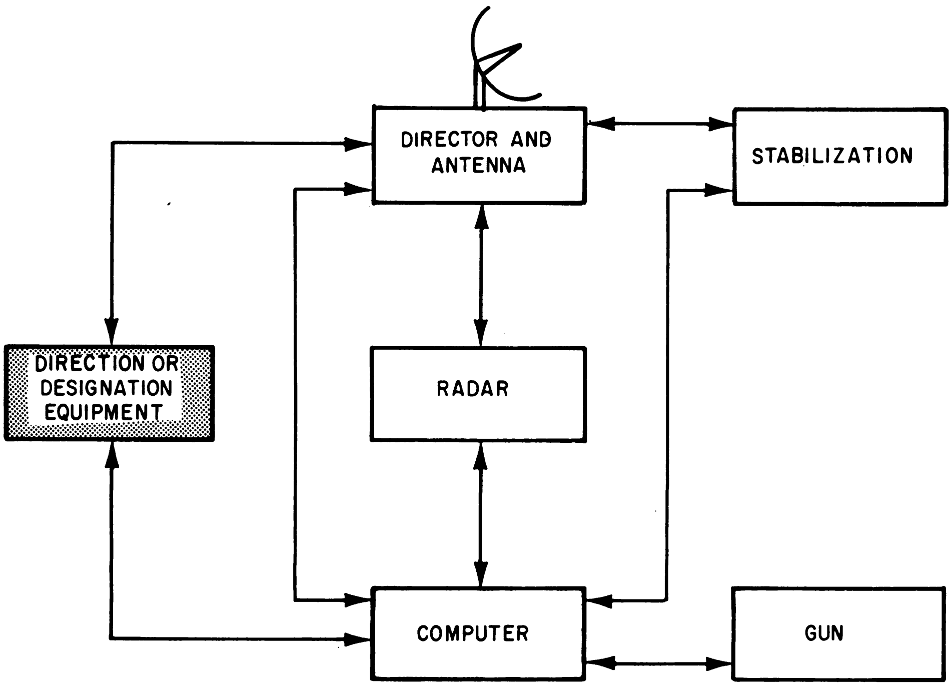

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Figure 10-1.—Direction or designation equipment assist fire control radars in acquiring a target.

A WCS is the nerve center of a complete weapons system, and has as its primary purpose the control of weapons fire on selected targets to ensure the maximum kill probability of the weapon. Note that this is a broad statement; it does not restrict the system to a particular type of weapon and it includes instruments that could be only indirectly involved in weapon control. A WCS is composed of a Weapons Direction System (WDS) and one or more Fire Control Systems (FCS) (fig. 10-2).

This chapter also gives a brief description of the Naval Tactical Data System (NTDS). Although maintenance of the NTDS is not your responsibility as an FT, you should be aware of the function it plays in the evaluation of targets and the assignment of weapons to these targets.

WEAPON SYSTEM OPERATION

As stated earlier, the purpose of a WCS is the control of fire on selected targets to ensure the maximum kill probability of the weapon. In order to do this, a target must be detected, evaluated, and designated to a fire control system.

Figure 10-3 depicts a typical weapons system aboard combat ships. Refer to this figure as the weapon system operation is discussed.

Target Detection

Target detection involves the surveillance and detection, or discrimination, of any enemy or unidentified targets that appear within an area of surveillance. This detection is normally achieved by the ship's search radars, and in some cases, by optical designators or fire control radars.

Target Evaluation

Target evaluation consists of identifying the target (friend or foe) and determining what weapon (gun or missile) is to be used to engage the target.

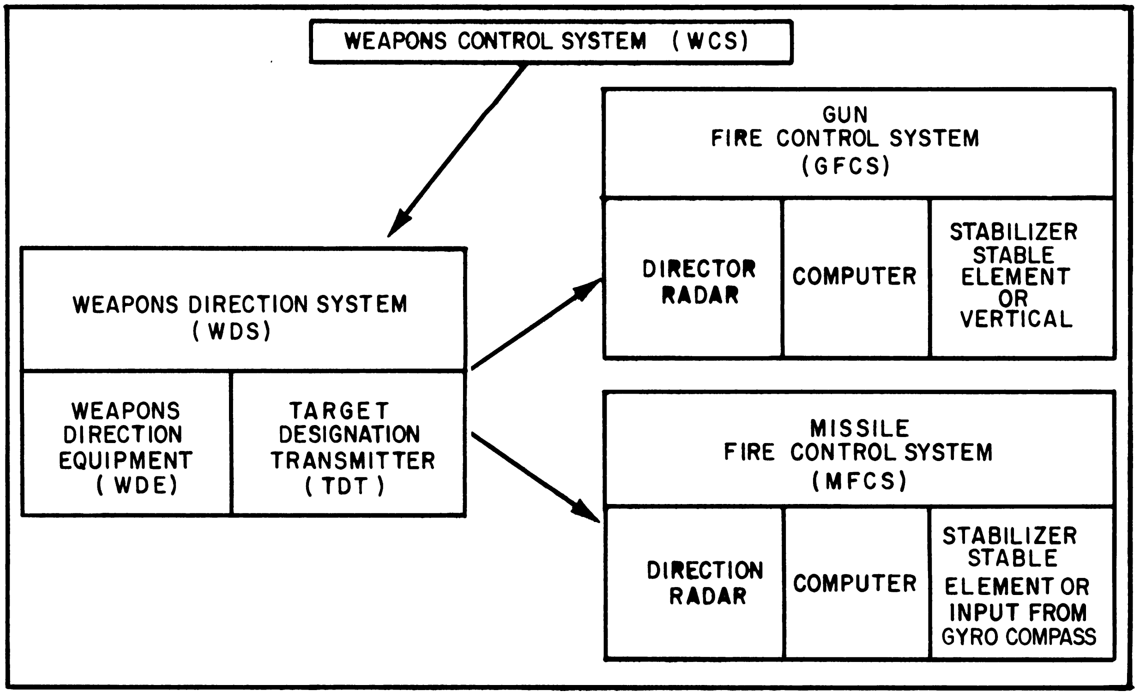
WEAPONS CONTROL SYSTEM (WCS)
GUN FIRE CONTROL SYSTEM (GFCS)
DIRECTOR RADAR
COMPUTER
STABILIZER STABLE ELEMENT OR VERTICAL
WEAPONS DIRECTION SYSTEM (WDS)
WEAPONS DIRECTION EQUIPMENT (WDE)
TARGET DESIGNATION TRANSMITTER (TDT)
MISSILE FIRE CONTROL SYSTEM (MFCS)
DIRECTION RADAR
COMPUTER
STABILIZER STABLE ELEMENT OR INPUT FROM GYRO COMPASS

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Figure 10-2.—Makeup of a Weapons Control System.

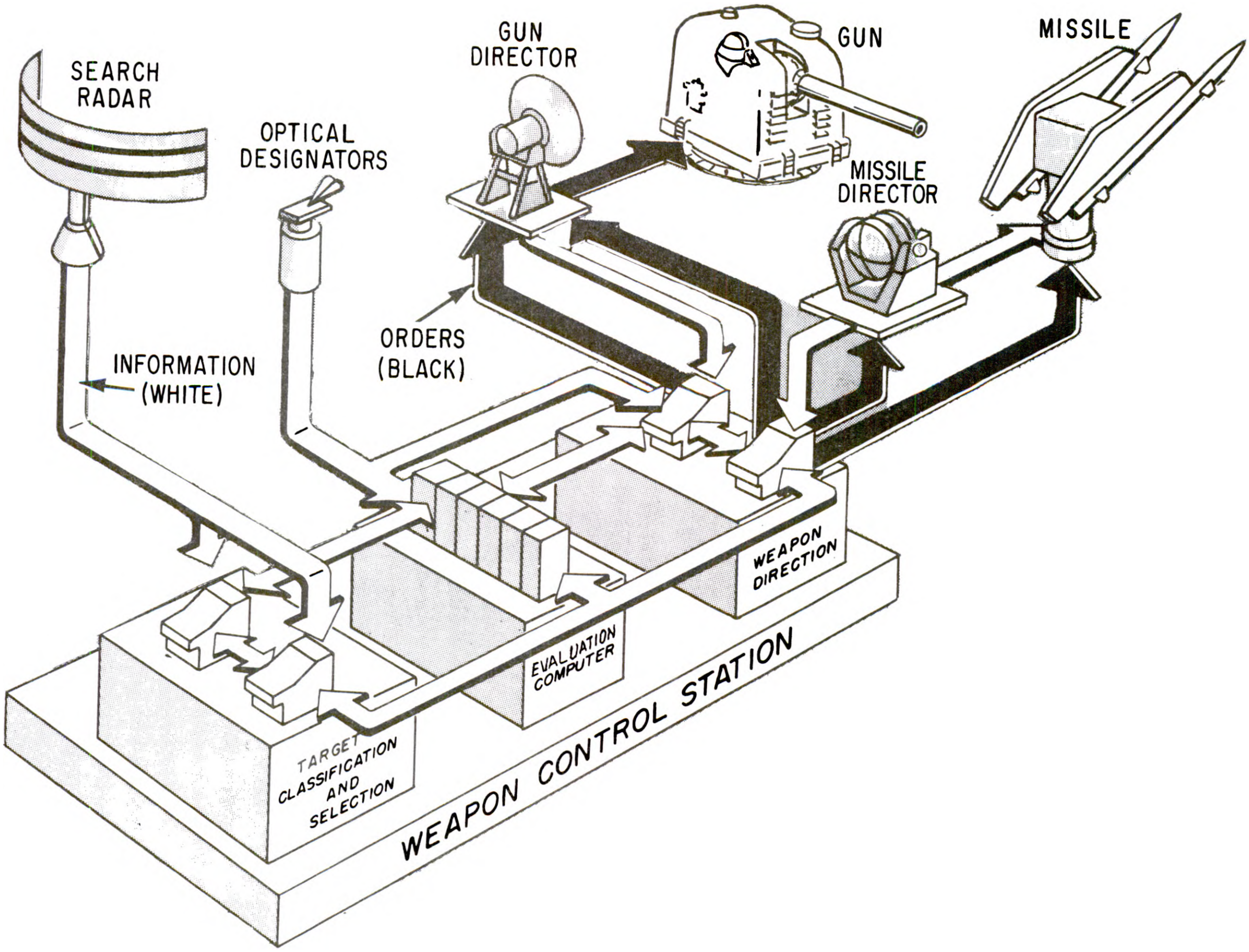

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Figure 10-3.—Weapon system operation.

To afford protection to friendly forces, IFF (identification friend or foe) electronic equipment is used in conjunction with the search radar systems. Through the use of IFF equipment, radar-detected targets can be identified as friendly without resorting to verbal communications or visual identification. An IFF transmitter emits a signal on a particular frequency. The signal is received by the target in question, and which in turn transmits a different coded signal back to the ship. If the ship's receiver is set to the particular coded pulse chain that is returned, it automatically signals the operators that the target is friendly. If no signal is returned or the code is incorrect, the target is assumed to be unfriendly.

There are many factors in determining what weapon is used to engage the target. Some of these are target speed, height, range, and the threat to ownship.

Target Designation

The target, since detection, and while being evaluated, is tracked across the sky or sea by the search radar or optical designators. The accuracy of these pieces of equipment is limited, but they are accurate enough to designate a fire control radar onto the target. Once the appropriate fire control system acquires the target, designation is released, and the fire control system engages the target.

The operation of a weapons system will be covered in greater detail later in this chapter, including the individual units which make up a WCS.

WEAPONS DIRECTION EQUIPMENT (WDE)

The WDE is the link in the WCS between the search radar and the FCS. Search radars detect and identify targets at long range. To successfully repulse an enemy attack, many decisions must be made long before the enemy comes within firing range. These decisions are based on target evaluation, which begins at the WDE.

TARGET EVALUATION

Each target is evaluated according to the threat it poses. Then, the FCS and weapon best suited to deal with each target are determined. Each FCS must be assisted in acquiring its assigned target(s), and a continuous appraisal of the tactical situation during the entire operation must be maintained. The length of time available for performing these operations is extremely limited. The WDE rapidly accomplishes these tasks and provides supervised and coordinated target evaluation and assignment.

The assignment of an FCS and its associated weapon is based on the evaluation of target threat. This evaluation is, in turn, based on the weapons available, and on the target's capability and probable intent. The ship's weapons are a known factor, but only an educated guess can be made as to target capability and intent. The target must be engaged at sufficient range to obtain a good probability of a kill before it can accomplish its mission. To do this, the FCSs and weapons should be brought to bear on the target as soon as possible. Tactical conditions, however, may not allow the use of certain weapons. In a multiple target attack, the threat that each target poses must be weighed to determine target priority and weapon selection. An estimate is made of the maximum range at which each target can effectively release its weapons. Weapon selection versus target priority is based on the weapon's maximum range and its kill probability.

The WDE graphically displays the location of all the targets and tracks selected ones. Target location data is continuously available for designation to an assigned FCS. The FCS's detecting equipment (optical or radar) searches a small volume of space, and an unaided FCS normally experiences some difficulties in acquiring a moving target. However, when aided by the WDE, the time between target designation and acquisition is greatly reduced.

The WDE is designed so that each station in the system performs only a part of the overall system job. Each partial job is initiated by a preceding act performed in a systematic schedule of events. Thus, at each station, the operator has only a limited number of decisions to make and a limited job to perform. In this way, target data is handled efficiently and with minimum delay.

WDE installations vary, but the major units and their functions are similar. The major operational units of a typical system are the Target Selection and Tracking Console, the Director Assignment Console, and the Weapons Assignment Console.

TARGET SELECTION AND TRACKING CONSOLE

The Target Selection and Tracking Console (TSTC) (fig. 10-4) receives inputs from a search radar and produces a PPI and a target height display. The display depicts the tactical situation about ownship as seen by a search radar. From the display, an initial evaluation of target threat is made. The range and bearing coordinates of threatening targets are inserted into automatic tracking channels. Successive target position inputs to each channel are used to calculate and correct target range and bearing rates. Each tracking channel provides a continuously generated target position in these quantities. Target height, when measured by a three-coordinate search radar is inserted in the

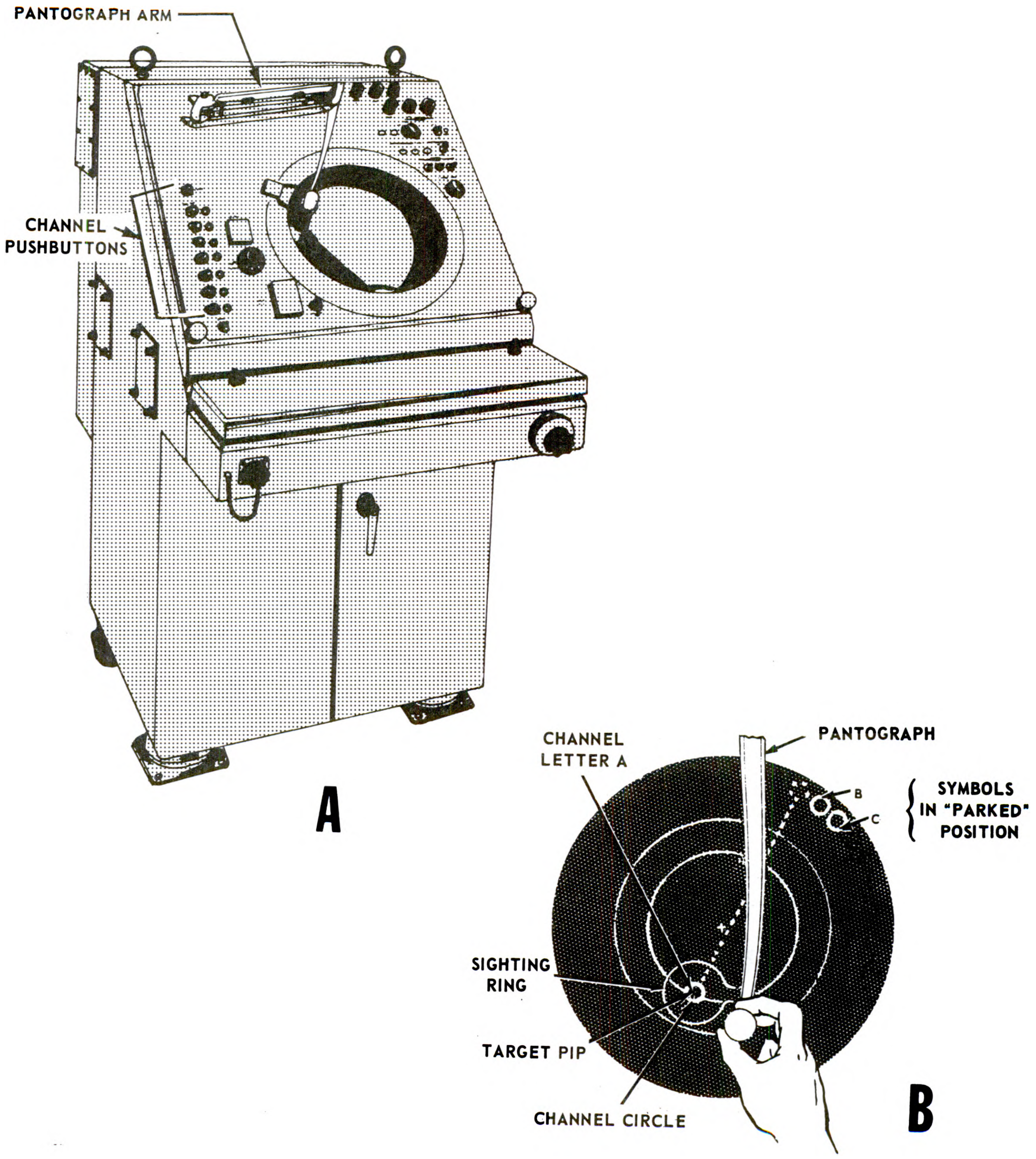

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Figure 10-4.—A. Typical Target Selection and Tracking Console; B. TSTC display.

tracking channel and memorized. The tracking channels on the TSTC are identified by letters. There is provision for six channels, lettered A through F. The numerals that appear on the PPI identify FCSs that are tracking targets. Any target that is being tracked in the tracking channels of the TSTC and forwarded to the Director Assignment Console (DAC) for further processing is considered hostile or of interest to the ship's FCSs.

Most installations have more than one TSTC. Normally, one console is used primarily for selecting targets and the others for tracking targets. Each console, however, has the same display. By having more than one console, the operational burden and the decision-making requirements of each operator are reduced. Remember that when handling target data, time and accuracy are important. Identification of targets is normally handled by the CIC, but the TSTCs have IFF challenge controls to permit last-minute identification. In an emergency, a TSTC can designate directly to the FCSs. For this reason the positions of the FCS directors and the clear bearing zone for missile firing are available for display. In normal operation, however, clear bearing zone is not displayed.

DIRECTOR ASSIGNMENT CONSOLE

The Director Assignment Console (DAC) (fig. 10-5) receives, on its PPI presentation, the position of all targets that are being tracked by the tracking channels of the TSTC. Here targets are evaluated and the best sequence to engage them is determined. FCSs are assigned to track targets and the best suited weapon to use against that target is selected.

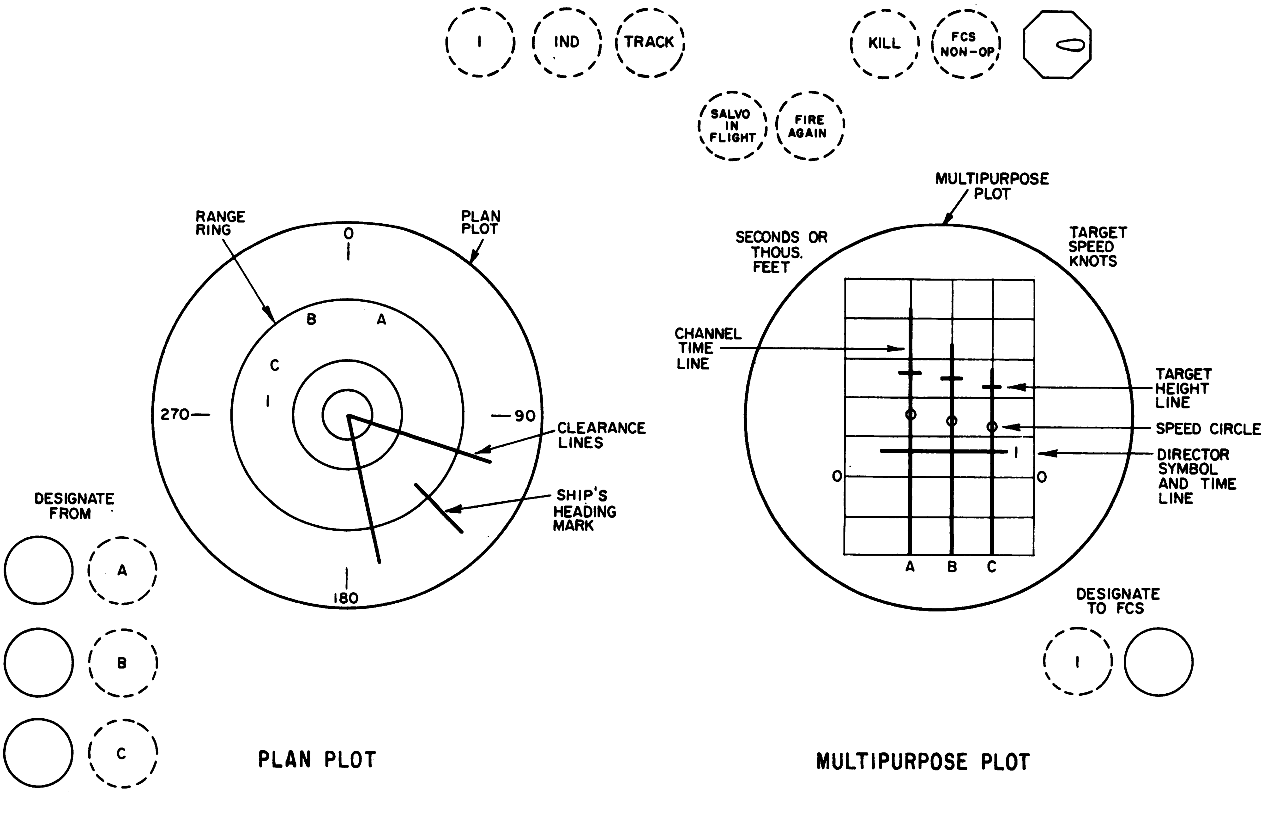

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Figure 10-5.—Director Assignment console display.

Many evaluation aids are employed on the DAC to help with the determination of a target's threat. These include target present position data, the missile clear firing zone, and ownship's heading line. The course of a target is also available on the DAC PPI scope.

In addition to the evaluation aids displayed in the PPI scope, another multiple purpose presentation indicates target height, target speed, and time factors for each target in a tracking channel. There are two time values displayed. One indicates the time within which a missile director must be assigned and a missile fired in order to intercept the target. This time factor is computed considering the time lapse between target designation to a Missile Fire Control System (MFCS), missile firing, and the flight-to-intercept point versus the target range and speed. The second time factor represents busy time for an MFCS. When the MFCS is in the air-ready mode the indicating line is stationary, representing a fixed value. After the MFCS acquires the target, but prior to firing the missile, the line moves to a position which indicates the approximate time of flight to intercept. Once the missile is fired, the line moves down the time scale and indicates an approximate time to intercept. Although based on the use of missiles, the time indications can be used with gun system for a good approximation.

A comparison of the evaluation aids displayed will dictate the correct FCS assignment. Once this decision has been made, the assigned FCS is mated to its selected target. The DAC designates the target coordinates to the FCS. The FCS, upon receiving designation signals, slews from the air-ready position to the designated range, bearing, and elevation. The FCS follows the designated data, modified by a search program, until it acquires the target. Targets being optically tracked by the TDTs are displayed in the DAC presentation. These have priority over all other GFCS targets. TDTs can designate directly to a GFCS, although normal operation is for the TDT designation to go through the DAC. Targets engaged by the ship's gun batteries are close aboard and are of immediate concern to the ship defense.

There is little time available, and the assignment of guns to an FCS must be prearranged by ship doctrine. Therefore, the assignment of GFCS by the DAC automatically includes the gun mounts associated with the system. The conditions which require missile selection, loading, and firing to be a function of the WDE are not present with a GFCS. GFCS controls the entire procedure once the order to commence fire is given.

TARGET DESIGNATION TRANSMITTER (TDT)

The TDT (fig. 10-6) is a manually controlled optical-sighting unit, located high on the ship's superstructure at the AAW (antiaircraft warfare) station. The TDT and control unit form a topside designation station. Their functions are to:

1. Generate, display, and transmit target bearing, elevation, and estimated range information

2. Display fire control system status

3. Provide switching control for selection of fire control systems to which the designation information may be transmitted

Two TDTs are installed at the AAW station, one on the starboard side and the other on the port side. Each TDT and control unit is manned by an operator.

The TDT operator tracks the target using binoculars mounted on the transmitter. The operator closes a switch on the handgrip to signal (on target signal) that the TDT is tracking a target. In this manner, target bearing and elevation are transmitted to the control unit and other stations on the ship (fig. 10-7).

Estimated range is cranked in manually to the control unit by the control unit operator. The control unit displays bearing, elevation, and estimated range, and designates this data to other stations whenever the control unit operator closes a target assignment switch.

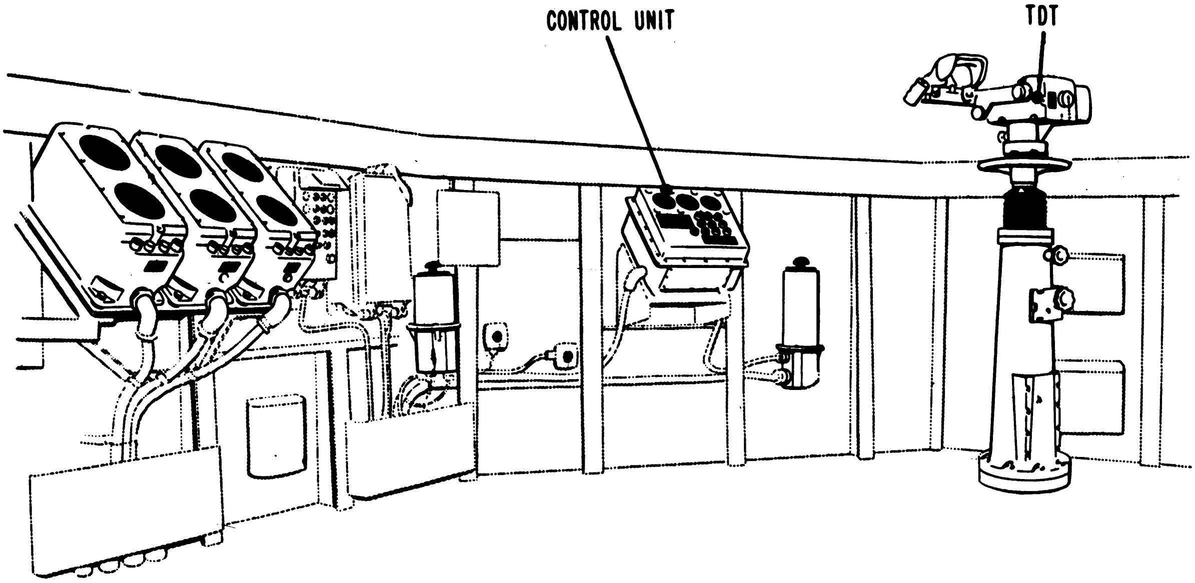

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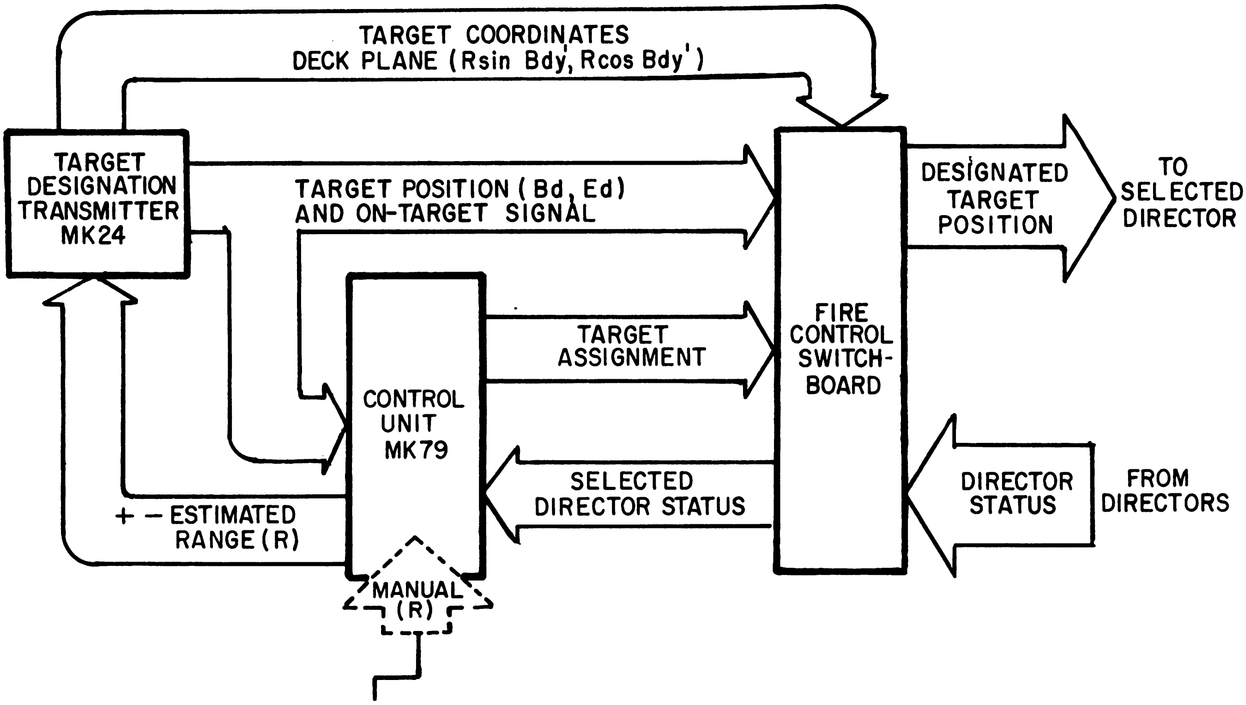
Figure 10-6.—Target Designation Transmitter (TDT).


TARGET COORDINATES
DECK PLANE (Rsin Bdy', Rcos Bdy')
TARGET DESIGNATION TRANSMITTER MK24
TARGET POSITION (Bd, Ed) AND ON-TARGET SIGNAL
FIRE CONTROL SWITCH-BOARD
DESIGNATED TARGET POSITION
TO SELECTED DIRECTOR
CONTROL UNIT MK79
TARGET ASSIGNMENT
SELECTED DIRECTOR STATUS
DIRECTOR STATUS
FROM DIRECTORS
+ – ESTIMATED RANGE (R)
MANUAL (R)

166.241

Figure 10-7.—Target Designation Transmitter and Control Unit, Functional Block Diagram.

WEAPONS DIRECTION SYSTEM OPERATION

Figure 10-8 shows the major units of a WDS and a simplified flow diagram of the operational relationship between major units. Notice that a missile fire control director and its computer, and a gun fire control director and its computer, are shown along with their delivery devices; i.e., a missile launcher and a gun mount. Remember, once a target has been acquired by an FCS, that system functions independently of the WDS in tracking the target and computing the launcher or gun orders.

Initially, the source of target information is usually a search radar. Inputs from the radar (fig. 10-7) are sent to three TSTCs. These consoles have identical information displayed, so we will describe the operation of the one located in CIC.

A typical TSTC and its PPI display are shown in figure 10-4. The console displays targets on a PPI presentation, which can be shifted to monitor various search radar displays, permitting system flexibility in the event of malfunction or poor reception of any one search radar. The display depicts the tactical situation about ownship at any given instant. From this display, the initial evaluation of target threat is made. Targets can be assigned to tracking channels and sent to the weapon control station TSTCs for tracking by placing the pantograph arm on the console directly over the target video on the radarscope. A small illuminated dot, which represents the position of the pantograph arm, will then be superimposed on the target video.

There are a number of tracking channels in this piece of equipment in order to keep separate the movement data of more than one target. Buttons which activate the tracking channels are located on the console and are identified by a single letter (A through F). To activate a tracking channel, the console operator presses a channel button. A small illuminated circle with the channel letter designation within it will appear in the same position on the PPI display as the dot for the pantograph arm. The presence of a tracking channel symbol superimposed on target video will cause the TSTC operators in weapons control to commence tracking that particular target.

The evaluator estimates the target's weapon release range (EWRR, estimated weapon release range). This is manually inserted into the WDS by the TSTC operator in CIC pressing the appropriate channel button and simultaneously making the input at an attached panel. This channel circuit activating prerequisite permits each tracking channel to have its own EWRR. Knowing the target's EWRR aids weapons control in making a director-to-target assignment. This is particularly true if multiple targets have been detected.

The tracking channels are divided between each tracking console in Weapons Control. The operators track only the targets assigned to their particular consoles. Tracking at the TSTC is rate aided. The rate is generated by repositioning the pantograph arm to coincide with any target movement. When the pantograph arm is moved and a rate-aid switch is activated, present target position data is inserted into the tracking channel. Successive changes of the arm position are electronically compared and a target rate is established. The rate-aided solution should keep the channel letter designator positioned on the target after only three or four pantograph corrections.

Tracking operators can insert target data only into a channel to which they have electronic access. This access is indicated by the presence of a small circle around the channel letter designator on the PPI scope. The operator gains access to a channel by throwing a switch on the pantograph arm or by pressing the appropriate channel pushbutton on the console.

Figure 10-9 shows the target height or altitude graduations that are inscribed toward the left on the radarscope of each TSTC. These graduations or indices increase from the bottom to the top of the scope, with each increment equal to 5000 feet. If a three-coordinate radar has been selected at the console, a video dot representing the target's height will appear adjacent to the height graduations. The video dot moves vertically in response to target height information from the radar. Target height is then visually apparent to the operators when they compare the dot's vertical position with the inscribed indices.

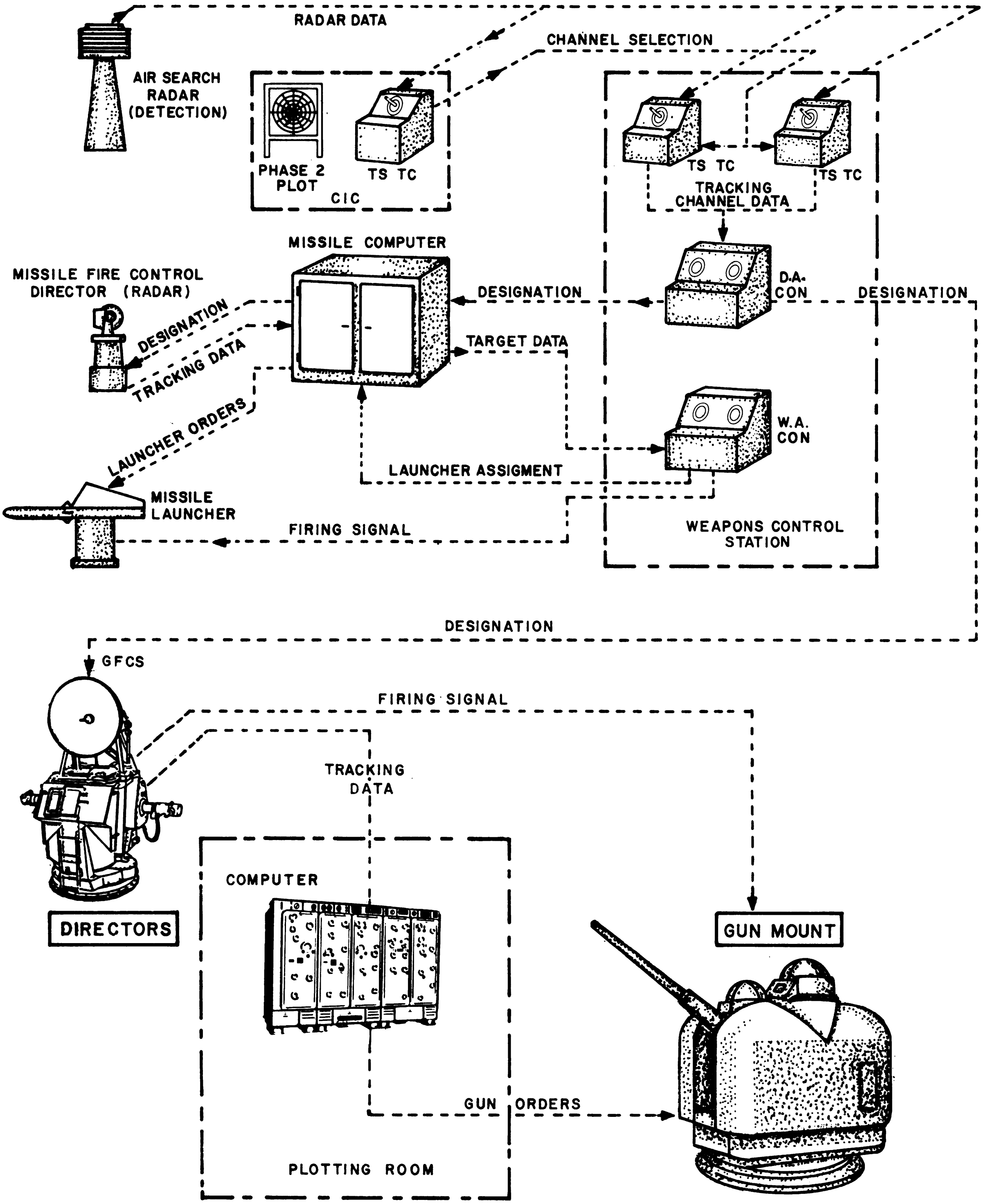


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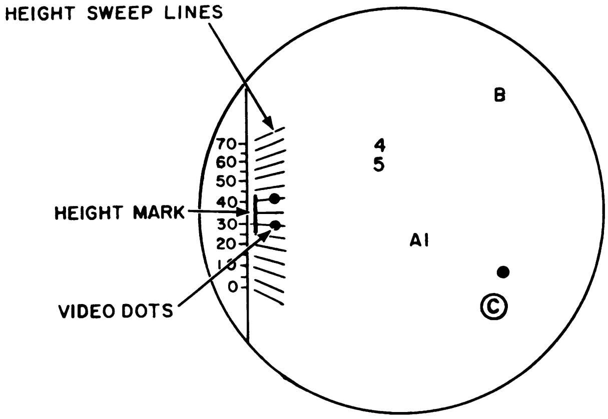
Figure 10-8.—WDS simplified data flow.



LETTERS INDICATE CHANNEL POSITION
NUMERALS INDICATE TRACKING FCS
CIRCLE INDICATES CHANNEL ACCESS
DOT INDICATES TARGET VIDEO

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Figure 10-9.—Tactical display of target selection and tracking.

Assigning the proper FCS to a target is very important in AAW. The DAC operator evaluates the target using the many aids mentioned earlier in this chapter.

Tracking data from a channel in the TSTC is fed automatically into the DAC. Two plots or scopes are provided on this console. They are called the plan and multipurpose plots (fig. 10-5). Target video is not present on these scopes, but the PPI shows target range and bearing by displaying the channel letter designators, the same as on the TSTCs. Target course and speed for a particular target are approximated on the PPI by a vector which has its tail attached to the channel letter. The vector's magnitude and direction correspond to target course and speed. (See channel A in fig. 10-5.)

Numerals which show the bearing and range of the directors are also displayed on the plan plot. The director numbers are always present, but a channel letter shows up only when a channel is tracking a target. All of the symbols (numbers and letters) are intensity modulated; that is, they show up on the scope as a video presentation. The directors on board ship are numbered in numerical order from forward to aft so that the relative location of each can be readily noted. All directors that are used in AAW have their numbers displayed on the director assignment console. The numbers are also displayed on the target selection and tracking consoles, provided the director is tracking. If director 1 is tracking channel B, a 1 would be superimposed on the B.

The plan plot also shows the ship's heading mark, which is a continuous indication of ownship's course. The radial lines on either side of the ship's heading marker also respond to the movement of ownship's course and represent the missile blind zone for an aft (rear) launcher installation.

The multipurpose plot is used for making time comparisons which enable the DAC operator to select the most threatening target for designation to a director. This plot permits the operator to plan ahead in case the directors are being utilized and cannot be assigned immediately. Target height and speed are also displayed on this plot to aid the operator in assigning the best director.

The multipurpose plot has a vertical video line for each tracking channel. The vertical length or height of the line is compared to inscribed indices on the scope which represent time. The vertical time lines are "programmed" to show when a director must be designated to a particular channel, so that a missile can be fired to intercept before the target reaches its estimated weapons release range. The factors which affect the height of the vertical line are target range and speed, fire control director acquisition time, weapon assignment time, and EWRR. Computations for these lines are based upon their application to missile fire control systems; however, approximations can be made which will apply to gun fire control systems as well.

Pushbuttons on the left side of the director assignment console are used to "designate from" a target data source. The source may be any one of the tracking channels, one of the optical target-designation transmitters (TDTs), or one of the fire control directors which has previously acquired the target. Your ship may have two or more TDTs located topside at AAW station(s). TDTs are used to designate targets which may have escaped radar detection. Designating from one director to another director is called interdirector designation; it is by far the most expeditious method, since the target is more accurately pinpointed by fire control radar.

Pushbuttons on the right side of the console are used to "designate to" a fire control system. There is a pushbutton for each fire control director, arranged in numerical order from top to bottom on the console.

To assign a director to a target data source, the console operator merely presses a "designate from" pushbutton simultaneously with a "designate to" pushbutton. For example, if you want director 1 to track a target in channel C, depress the C in the "designate from" column and the 1 in the "designate to" column simultaneously. If you want director 1 to track director 2's target, depress the 2 in "designate from" along with the 1 in "designate to." (The total number of directors and data sources is not shown in figure 10-5 for the sake of clarity.)

Circuits are then activated which automatically slew the director to the target in range, bearing, and elevation. Remember, the accuracy of the elevation information depends on the reliability of target height data. Range and bearing accuracy depends primarily on the tracking ability of the TSTC operator. It is assumed that the equipment is aligned and functioning properly.

A director is released from designation when it "sees" the target with its own equipment or when the DAC operator presses a designation "release" pushbutton on the right side of the console. The "release" pushbutton must be depressed at the same time as the director's "designate to" pushbutton.

NAVAL TACTICAL DATA SYSTEM (NTDS)

NTDS is a high-speed digital, data-processing display, communication, and data conversion system that provides tactical data used for effective fleetwide defense against all types of enemy targets. The NTDS coordinates collection of tactical data from sources both internal and external to ownship. Ownship data inputs to NTDS are received primarily from search radars, IFF equipment, electronic warfare (EW) equipment, sonar, navigation, and communications equipment. These data inputs are supported by inputs received from other ships, aircraft, and shore stations via data links. The NTDS correlates this data for a clear representation of the tactical situation, processes the data as required to aid in the decision-making process, and communicates all action decisions to the WDS.

The NTDS has three basic purposes:

1. Generation of target descriptions
2. Presentation of the tactical situation
3. Communication of tactical data

System components (fig. 10-10) include a variety of electronic equipment, such as:

Automatic, high-speed, general-purpose, stored-program, solid-state computers
Displays
High-speed digital, data communication facilities
Radar video processors
Readout devices
Magnetic tape handlers
Manual data-entry devices
Analog-to-digital converters

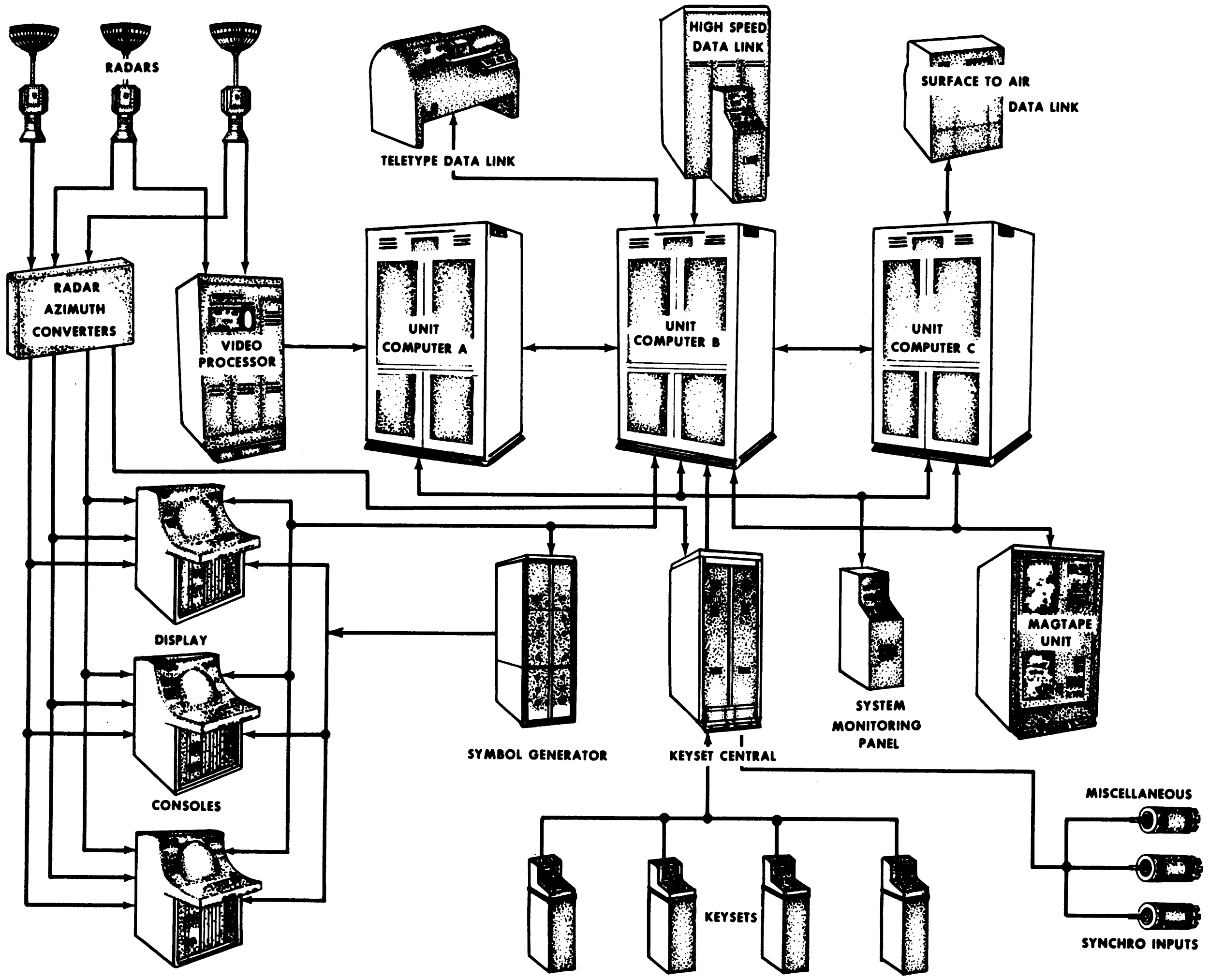

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Figure 10-10.—Naval Tactical Data System diagram.

The computers perform data-handling calculations and derive information required for threat evaluation, weapons assignment, dead-reckoning navigation, and communications by way of data links. They also track, identify and determine the height and size of the unknown force. All tactical data are represented visually on display consoles.

The NTDS provides three separate communication links.

1. The A-link (link 11)
2. The AN/USC-2 link (link4A)
3. The B-link (link 14)

The A-link is a long-range digital communication link between tactical data units (ships and/or aircraft). Three basic types of information may be received and transmitted by way of this link.

1. Target tracks
2. Weapons status and orders
3. Control messages which regulate the operation of the data link network

During normal operation, the data exchanges between NTDS ships proceed automatically and continually. The unit computer that controls the link equipment is in direct contact, via radio, with unit computers on all other NTDS ships in the force.

The AN/USC-2 data link is used to communicate automatically between the ships and aircraft equipped with this data link. Guidance instructions to interceptors or bombers may be transmitted via this link.

The B-link provides automatic broadcast of tactical data from NTDS-equipped ships to non-NTDS-equipped ships via radio teletype facilities. Generally, one NTDS ship is designated by the officer in tactical command to broadcast NTDS track information to nonNTDS units in the task force. This link may also be used to transmit NTDS data to shore installations.

With the entire tactical situation on visual display and the status of all weapons indicated, the tactical commander is able to best employ defensive units (aircraft, missiles, or guns). Merely by pressing the required button, the tactical commander can assign the desired unit instantaneously. Target track and control data are then automatically transmitted to the assigned unit to effectively engage the target by the best means available to it.

CHAPTER 11

OVERVIEW OF GUN FIRE CONTROL SYSTEMS

The term "fire control" means the directing of various weapons so that they will hit a desired target. One way of accomplishing this is with a gun fire control system (GFCS). A GFCS is comprised of a group of instruments working together to direct a weapon to the desired target. Figure 11-1 is a block diagram of such a system. Figure 11-2 depicts the actual instruments that make up a gun fire control system. Careful comparison of the two figures should enable you to relate them.

In this chapter, we apply the basic principles, the basic components, and the equipment already covered in this RTM to the GFCS Mk 68, the GFCS Mk 86, the Close-In Weapon System (PHALANX), and the Harpoon Weapon System. Since it is impractical to cover all the modifications (mods) of these GFCSs, a representative of each system has been selected. Keep in mind that there are variations between different mods of a system (number of guns controlled, designation sources, digital or analog computer, etc.), but for the most part, the functional descriptions of GFCSs do not vary to any great extent.

GUN FIRE CONTROL SYSTEMS

Coverage of the GFCSs is limited to the primary functions of the major units in the systems, their modes of operation, and the data flow into the system and between the major units in the system. Before dealing with the systems themselves, let us review some of the common characteristics of the major units in all GFCSs. There are three common characteristics (invariants) in the fire control problem—the line of sight (los), the lead angles (sight angle and sight deflection), and the line of fire (lof). Somewhere, in each system, these three factors are established, and can be used as a basis for expressing the primary functions of the major units.

The director normally establishes the los, which is used to define the target's present position. This is accomplished by either optical means or radar equipment. The target position of importance is its position at the instant the gun is fired. Therefore, the director or radar must provide a continuous measurement of target present position so that it is available when the gun fires. The director tracks the target by keeping the los on it. This not only provides a continuously changing los, but it also furnishes a means of measuring the rate at which the target is changing its position with respect to ownship. The relative rates are needed to compute the lead angles. The director is located high in the ship's superstructure to increase its horizon and to provide an unobscured field of vision.

The lead angles, the second invariant in the fire control problem, are calculated in a computer. The computer is located in a protected compartment. Gun ballistics and relative motion data are used to solve for the lead angles, which are added to the target present position to establish an aiming point.

The lof, the third invariant in the problem, defines the position of the aiming point. The gun orders describe the location of the lof. Thus, the primary function of the computer is to compute lead angles so that the lof can be established.

The fire control computers use the horizontal and vertical reference planes to compute the lead angles, while the director and

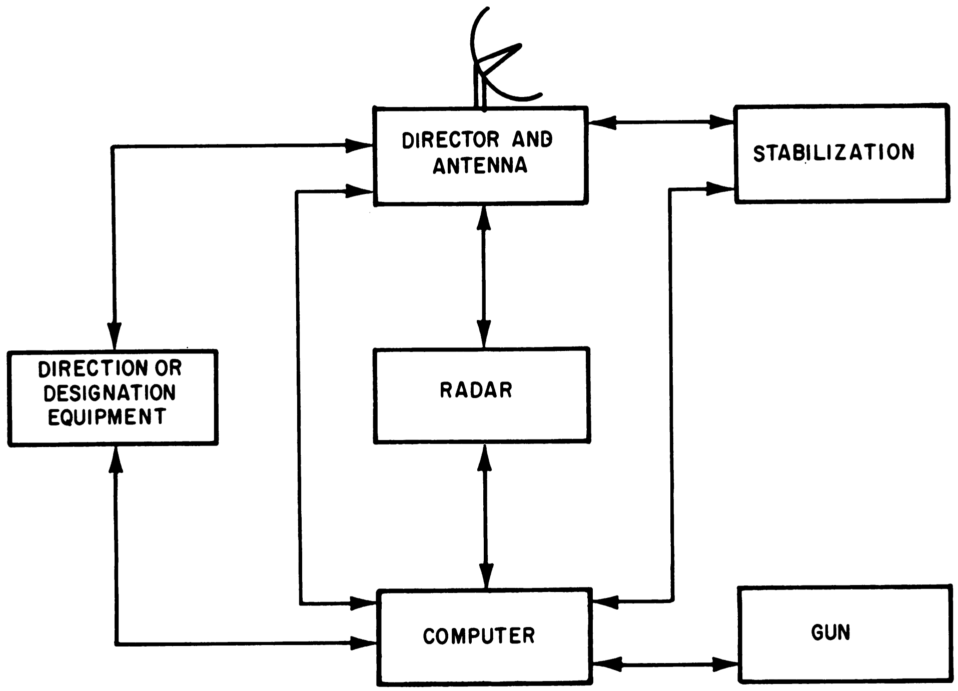

Figure 11-1.—Gun fire control system (GFCS).

the gun mounts move with respect to the deck and normal reference planes. Therefore, a stabilizing unit, either a stable element in the plotting room or a stable element gyroscope in the director, furnishes level and crosslevel signals to establish the horizontal reference plane in the computer. The primary function of the stable element is to furnish stabilization signals for the system.

The gun mount can be considered as the "reason for being" of a weapon system and must be considered as part of the system. It receives gun orders from the GFCS and positions the gun barrel to the lof. When ordered, the gun is loaded and fired at the target.

The units of the system are interaligned to a reference point located in a common reference plane. All measurements are made with respect to this point. Corrections for the effects of roller-path inclination and parallax are made to compensate for the displacement of a unit from the reference point or plane. The units are interconnected by transmission systems and are tied into the transmission systems by rotary switches. The primary functions of a GFCS are to provide the following:

- Continuous automatic gun positioning
- Continuous automatic fuze setting for mechanical time fuzes
- Continuous sight angle and sight deflection indications at the guns
- Control of the firing circuits to the guns

GUN FIRE CONTROL SYSTEM MK 68

The GFCS Mk 68 (fig. 11-2) is a dual-purpose system used to control 5"/54 gun batteries. The system can track and obtain a

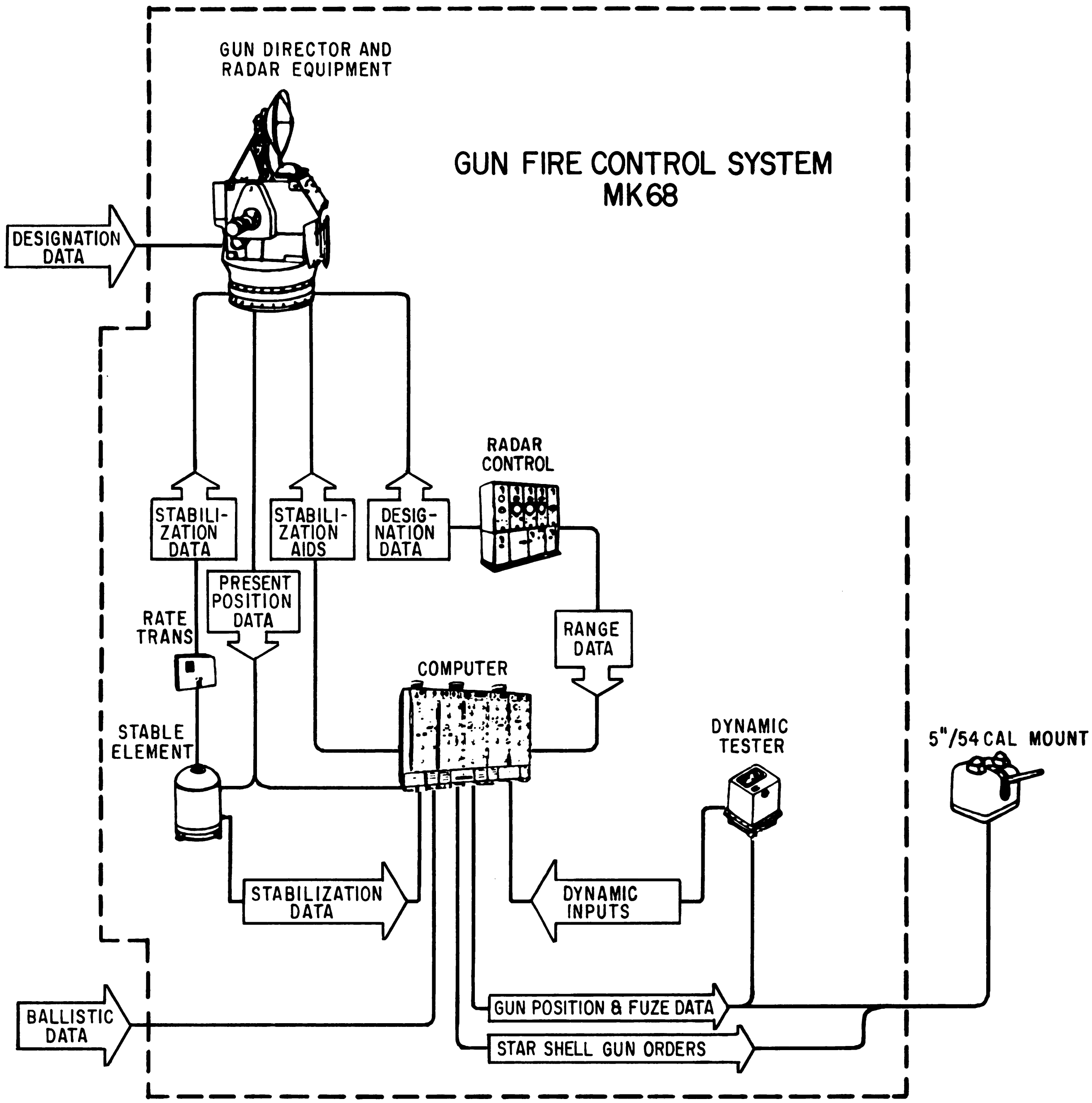

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Figure 11-2.—Major units in the GFCS Mk 68.

firing solution for AA sonic, AA supersonic, or surface targets. The major components of the system and the functions of each are as follows:

- Gun Director Mk 68 serves as the gun battery control station and provides the present position of the target to the computer.

- Radar Set AN/SPG-53 is used for automatic tracking of targets and supplies present range to the computer and angle error signals to the director power drives.

- Computer Mk 47 receives target position data, ownship motion data, and ballistic data, and computes the gun orders for the 5-inch guns.

- Computer Mk 116 is used in conjunction with Computer Mk 47 to produce star-shell gun orders for the 5-inch guns.

- Stable Element Mk 16 establishes the stabilized horizontal reference plane and provides the director and the computer with stabilization signals.

GUN DIRECTOR MK 68

Gun Director Mk 68 determines the present position of a target by establishing the los with either optical or radar equipment. The optical equipment consists of the director officer's open sight and binoculars mounted on a movable sight bracket, a tracker's telescope, and a stereoscopic rangefinder. There are three operator stations in the director—the director officer (DO), the tracker, and the rangefinder operator (fig. 11-3).

The radar is an automatic tracking lock-on type. Its operating controls are located in the radar console below decks. The radar has a range and a train operator. The range operator also controls the elevation system. The radar is an integral part of the director control system and provides angle error signals to the train and elevation power drives during the automatic tracking mode.

Director Power Drives

The director has individual amplidyne power drives in train, elevation, and crosslevel. The crosslevel power drive moves the director shield so as to keep the elevation axis of the optics and the radar antenna aligned with the horizontal

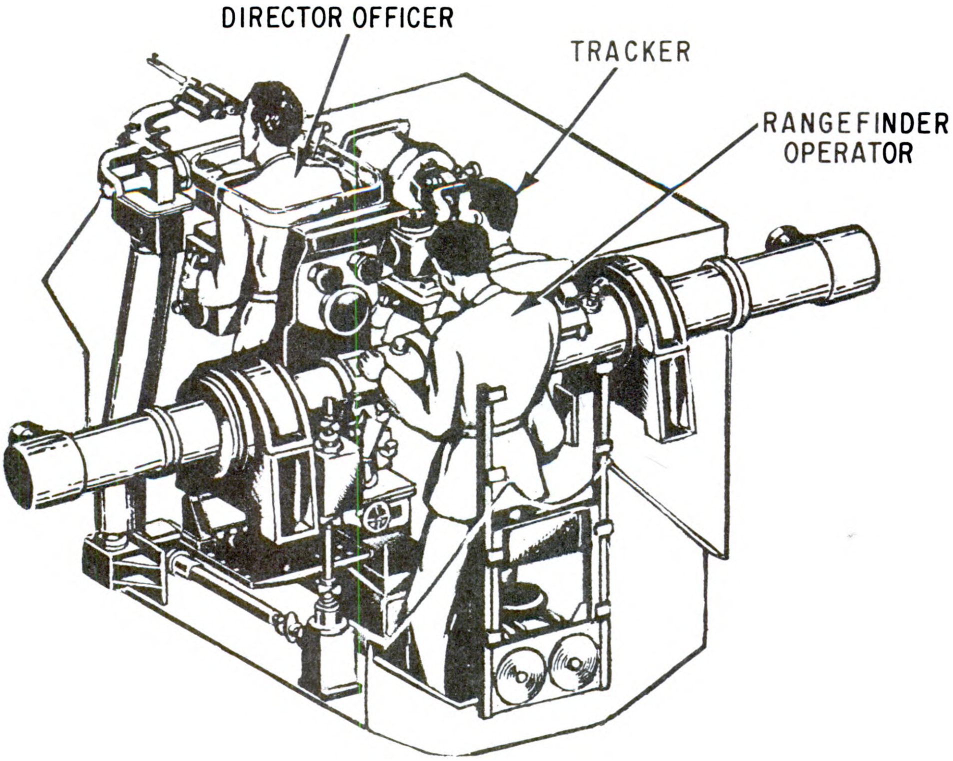

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Figure 11-3.—Director stations.

reference plane established by the stable element. For this reason, director elevation is measured in the vertical plane. The crosslevel power drive is operated either in the automatic mode of operation or in standby. This is controlled by the DO, who has control of the circuits to energize all the director power drives.

Train and Elevation Power Drives

The train power drive rotates the entire director to position the los in train. The elevation power drive rotates the optical equipment and the radar antenna about the elevation axis to position the los. The theory of operation of amplidyne power drives was covered earlier; therefore, only their operational controls and procedures are discussed in this chapter.

TYPES OF CONTROL.–The power drives have two types of control–handwheel and normal. The type of control used is selected by the DO at the control panel. Handwheel control is used against slow-moving surface targets. The elevation handwheel control unit is operated by the DO. The train handwheel control unit is operated by the tracker. Rotating the handwheels provides a drift-stabilized, low-rate control signal for the power drives. Normal control is used against all other types of targets.

Normal control has the following modes of operation:

- Auto-track–The radar is locked on target and has control of the power drives.

- Console mode–The radar has control of the power drives, but it is not locked on target; the handwheel and the indicator scopes in the radar console are used to establish and position the los.

- Director officer control mode–The DO's one-man control (OMC) unit and optics are used to establish and position the los.

- Tracker control mode–The tracker's OMC and telescope are used to establish and position the los.

- Target designation mode–The power drives slew to the designated position. (The power drives operate as velocity control servos in all modes except the target designation mode. In the designation mode, the power drives operate as position control servos.)

The mode of operation precedence circuits determine the order in which the operators can assume control of the director power drives. The order of precedence in normal control is as follows:

1. Director officer's OMC

2. Target designation

3. Radar auto-track

4. Console, and trackers OMC

The mode of operation is selected by the DO and is determined by the tactical problem to be solved. First, the DO selects either the normal or handwheel type of control with a switch on the control panel. With the switch in normal control, the DO can select the mode of normal operation with the left- and right-hand trigger switches on the OMC. The right-hand key gives control to the DO's OMC regardless of which mode of operation the director was in prior to this action. The left-hand key energizes the relays which set up the precedence circuits.

The control circuits from the various stations are interlocked so that the mode of operation can be changed in a logical sequence. When the DO pushes the accept target designation pushbutton on the control panel, the director goes into the designation mode of operation. Hence, the first two modes give the DO control of target selection. The remainder of the modes are selected in descending order of priority. The DO can select either optical or radar console track by means of pushbutton on the control panel. Pushing the pushbutton, gives control to the console over the tracker's OMC (optical track).

Present Range

Present range can be measured by the rangefinder or the radar. Since the radar can measure range continuously, it is the preferred source. The rangefinder measures range intermittently. The range selector switch determines the source of the range input to the computer.

Firing Circuits

The firing circuits from the director to the guns are energized and completed through the fire control switchboard in the plotting room. In the director, the firing circuit passes through a three-position switch in the DO's control panel. The switch positions are NORMAL, CHECK, and CEASE. In the NORMAL position, the firing circuit may be completed by the DO's portable firing key or the right-hand trigger switch of the tracker's OMC unit. With the firing circuit completed through the fire control switchboard and at the gun mount, the guns fire when either one of the director keys is closed.

When the DO's selector switch is in the CHECK position, both the firing and cease-firing circuits are open. When the selector switch is in the CEASE position, the cease-firing circuit is completed, sending a tone signal to the gun to indicate that firing is indefinitely suspended.

RADAR AN/SPG-53

Radar AN/SPG-53 can "lock on" and keep the los pointed at the target by controlling the director power drives. All operating controls are at the console (fig. 11-4). The set is controlled by the range operator and the radar trainer. It supplies present range to the computer and angle-error signals to the director train and elevation power drives.

In the console mode of operation, the radar operators use the handcranks and slew controls in range, elevation, and bearing to keep the los on target by observing the target echo on the

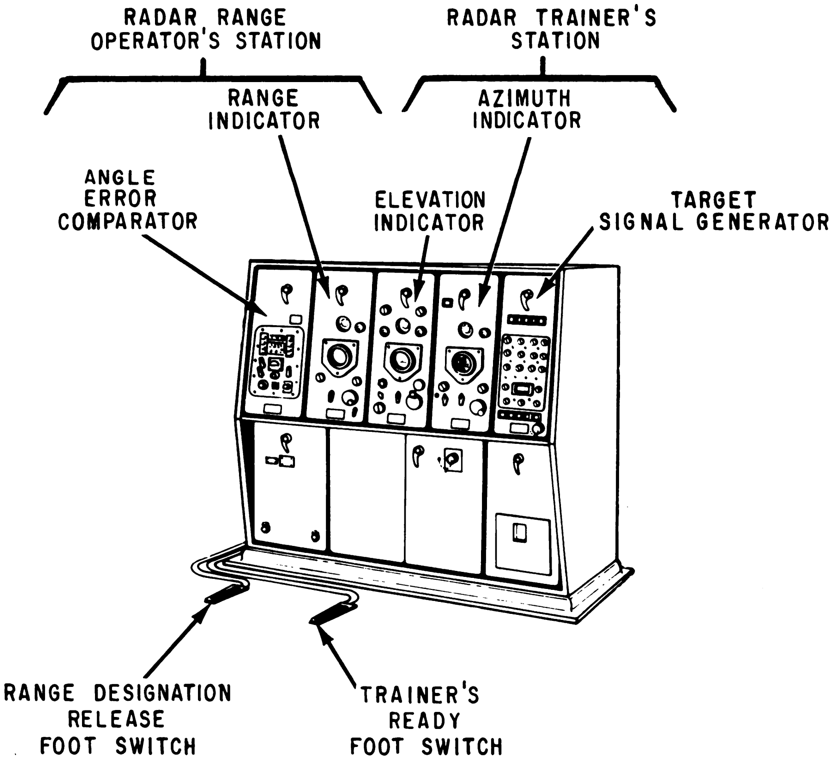

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Figure 11-4.—Radar operating stations.

indicator scopes. In the auto-track mode of operation, the target echo is centered on the radar scopes by either the console controls or by the OMC units in the director. With the los on target, the trainer presses the foot switch to energize the automatic tracking circuits and to lock the radar on target. The radar's error detecting circuits then provide signals to keep the director's los pointed at the target and the radar range correct. In the designation mode of operation, the director is slewed to the designated position and radar range is driven to the designated value.

When a target echo does not appear on the radar scopes, a search program is started. The radar range operator can take control away from the designation range signal by pressing the designation release foot switch. When the target echo does appear, the radar operators center the echo on the scopes by using their handcranks. When centered, the trainer presses a foot switch to shift the mode of operation to auto-track.

COMPUTER GROUP

The computer group of the GFCS Mk 68 is located in the plotting room below decks and may consist of Computer Mk 47 and Computer Mk 116. First, consider Computer Mk 47. It solves the fire control problem of producing gun orders for a 5"/54 gun battery. In addition, it is a dual-purpose computer designed to solve the AA and surface problems. (The basic fire control problem was described earlier and is not repeated in this chapter.) Since airborne targets travel at high speeds and are highly maneuverable, they allow little time for engagement. The computer must be fast acting and almost entirely automatic. On the other hand, the computer must be sensitive enough to detect and solve for the small, slow-generating errors that are present in the relative motion problem of a surface target. The duration of a surface engagement is relatively long, which means that when these errors are left uncorrected and are generating, they grow in size. The errors are critical, particularly at long ranges, and could result in missing the target. The computer is flexible and can handle both types of targets.

Automatic Control

Automatic control is the normal method of computer operation. It is divided into modes of operation by the type of target-surface, AA sonic, or AA supersonic. In automatic control, the computer receives continuous target position data from the director and radar, stabilization data from the stable element, and ownship course and speed from the master gyro and pitometer. It solves the relative motion problem by automatic rate control and supplies the director with the generated quantities and stabilization signals necessary to keep the los on target.

The major difference between the modes of operation is the scale factor used to change the operating limits of the rate-generating computing loops. The scale factor enters into the relative motion problem by way of the time line and is increased with a shift from the surface mode to the AA supersonic mode. This method allows the same computing loops to handle rates produced at slow surface speeds and at supersonic speeds.

Another difference is that in the surface mode of operation, the output from the vertical rate of target motion computing loop is not used. The reason for this is obvious. Surface targets do not have vertical rates.

Once the computer has been set up for automatic control, the operator's main function is to monitor it for correct and smooth operation. But, during certain types of fire, particularly surface fire, the computer may have to be shifted to local control, manual rate control, or the optical range mode of operation. This depends on the tactical problem to be solved. The computer operators have definite assigned tasks to perform during these types of fire. We do not cover the details of the operators' duties for each type of fire. Such a description would, for the most part, be dependent upon established gunnery doctrine. Instead, we describe computer operation in a general manner.

Local Control

In the local control mode of operation, the los does not originate in the director. The source of the data used to establish the los in the computer is from outside the GFCS. Target position is manually set into the computer by handcranks. Local control is used for indirect fire, a method used to fire at shore targets.

Manual Rate Control

It is sometimes an advantage to manually rate control when slow relative rates are present in the fire control problem. Solution time is reduced and the solution is obtained more smoothly. The computer operator has an overall picture of the tactical situation and is in an ideal position to correct the rate errors without over or under rate controlling. The rate control corrective signals are introduced by handcranks on the computer.

Optical Range Mode of Operation

In the optical range mode of operation, a continuous correct observed present range is not available to the computer. The range servo receiver is deenergized so that the present range in the computer does not automatically follow the observed present range signals. The computer's range system becomes a regenerative network, where increments of generated range are used to keep the present range correct in the computer. When a correct observed range is available, the computer operator uses a handcrank to correct the computer's present range. Range must be manually rate controlled in this mode of operation.

Designation Mode of Operation

In the designation mode of operation, the computer receives, from the designation equipment, the target position in north-south and east-west rectangular coordinates measured in the slant plane of the los. The computer converts the rectangular coordinates into polar coordinates of range and bearing. This data is sent to the director and aid it in acquiring the target. The computer converts the polar coordinates of director position into rectangular coordinates and feeds this data back to the designation equipment for display of the director's position. This latter function of the computer is performed in all modes of operation. Designated target elevation does not go through the computer, but, when available, is sent to the director from the designation equipment.

Wind Track Mode of Operation

Ballistic wind is a fictitious wind of constant velocity and direction. It has the same effect as the sum of the effects of the actual wind throughout the trajectory of the projectile. One method of obtaining the ballistic wind is to track a weather balloon. The course of the balloon is the ballistic wind course and the speed of the balloon is the ballistic windspeed. In the wind track mode, the computer uses this method to determine the ballistic wind. The director tracks the balloon and the computer operates as for AA tracking. The computer generates the relative motion rates and the rectangular coordinates of the balloon's position with respect to true north and the horizontal plane. From these values, wind data is computed and transmitted to a wind indicator, where it is used to compute the ballistic wind.

STABLE ELEMENT MK 16

The primary function of Stable Element Mk 16 (fig. 11-5) is to provide the fire control system with a stabilized vertical/horizontal reference frame. Its operation is fully automatic. All inputs and outputs are transmitted electrically, except for the latitude correction setting. The outputs are the position signals of level and crosslevel to the Computer Mk 47 and the Director Mk 68, and level rates of change to director amplifier Mk 76. Since the director's train and elevation power drives are velocity controlled, the rates of movement of the stable element level drives are transmitted via Rate Transmitter Mk 36 to the director. The rate signals are sent to the director as part of the generated quantities to stabilize the director's los in elevation.

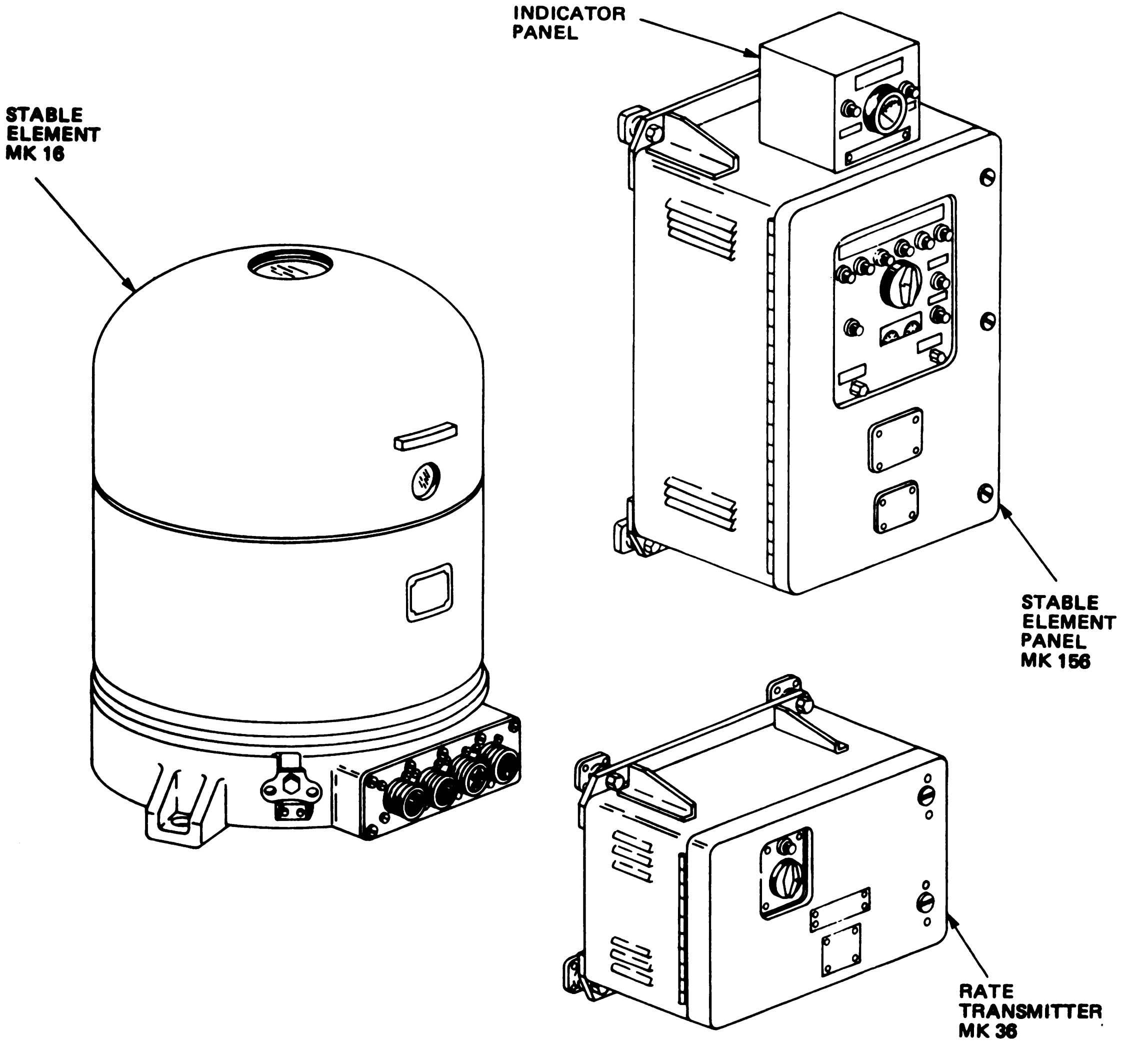

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Figure 11-5.—Stable Element Mk 16 and associated equipment.

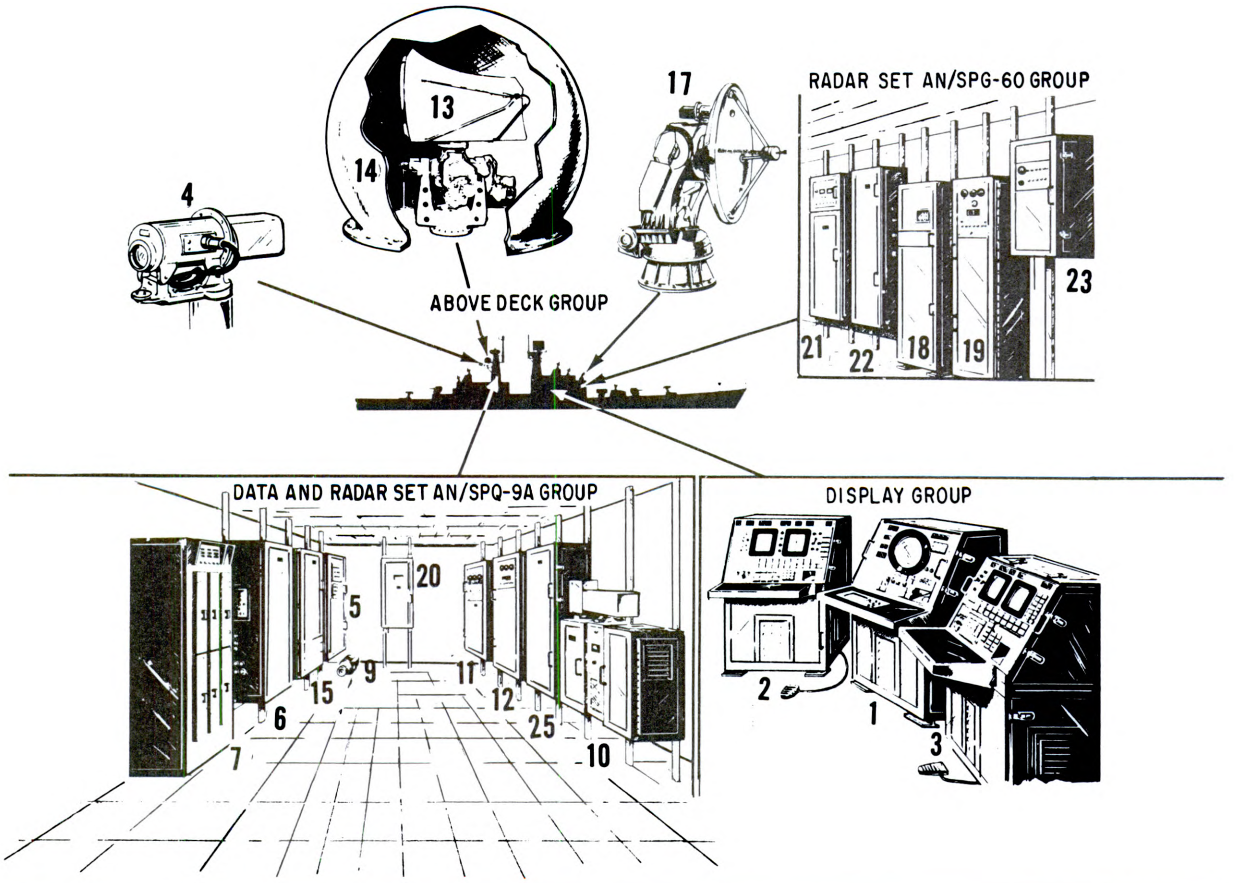
GUN FIRE CONTROL SYSTEM MK 86

The GFCS Mk 86 (fig. 11-6) was designed to utilize a general purpose digital computer for solving the fire control problem. The system has antiair, surface, and shore fire capabilities using the 5"/54 lightweight gun mounts.

In addition to the general purpose digital computer, the system features an air track radar, a surface search radar, and a sophisticated TV optical sighting system. This provides a capability for visually identifying targets, directing and spotting gunfire, and assisting the radar in tracking. No topside manning personnel are required for this system.

OPERATIONAL FEATURES

The GFCS Mk 86 has a highly effective engagement capability against surface targets. A high-resolution, track-while-scan surface radar provides for the automatic tracking of up to four selected targets. It also can display a clear



UNIT NO.	NOMENCLATURE
1.	CONTROL OFFICERS CONSOLE
2.	GUN CONTROL CONSOLE
3.	GUN CONTROL CONSOLE
4.	OPTICAL SIGHTING SYSTEM
5.	POWER CENTRAL
6.	SIGNAL DATA TRANSLATOR
7.	DIGITAL COMPUTER MK 152
8.	DIGITAL I/O CONSOLE
9.	MOTOR GENERATOR
10.	RADAR RECEIVER
11.	ELECTRONIC FREQUENCY CONVERTER
12.	RADAR TRANSMITTER
13.	ANTENNA
14.	RADOME
15.	CONTROL AMPLIFIER
16.	NOT USED
17.	RADAR ANTENNA MK 39
18.	RADAR RECEIVER
19.	RADAR TRANSMITTER
20.	SIGNAL DATA CONVERTER
21.	ANTENNA CONTROL
22.	SIGNAL DATA CONVERTER
23.	POWER DISTRIBUTION CONTROL
24.	READY SPARES CABINET (NOT SHOWN)
25.	VIDEO PROCESSOR

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Figure 11-6.—Gun Fire Control System Mk 86.

plot of targets within range while automatically tracking these four targets. The speed and capacity of the system computer, and the long-range detecting capability of the surface radar, provide a fast reacting system with a high rate of effective long-range fire power against shore and surface targets. The ability of the computer to maintain a dead-reckoning track, or to utilize radar data in determining true bearing and range from landmarks or beacons, permits effective direct and indirect shore fire.

The integral air and surface radar systems of GFCS Mk 86 enable both high- and low-altitude tracking at extended ranges. Long-range air search radar, by designating targets, permits the computer-controlled air track radar to provide early automatic acquisition, lock-on and tracking of targets. Essentially, the Mk 86 system surface radar complements the air search radar coverage. Both radars operate concurrently without interruption of individual search or track functions.

A portion of the remote optical sight is boresighted with the air track radar for visual observation in low-level and counterbattery (returning fire on enemy guns) situations. The GFCS Mk 86 also functions with the TARTAR guided missile system. It tracks and illuminates the target and provides precise target data to the missile system.

The three functionally and physically separated sensors (surface radar, air radar, and optical system) provide the system with flexibility for all types of targets.

MAJOR UNITS

The major components for all mods of GFCS Mk 86 are basically the same. There is no need to describe each Mod individually. Refer to figure 11-6 throughout the discussion on the major units.

Control Officer Console

The control officer console (COC) provides control and monitoring of the overall fire control system operation during a fire mission. The COC has a plan position indicator (ppi) display for radar video. Operating mode selection and target and gun assignments are performed at the COC. Target range, speed, course, and bearing from the computer are monitored at the COC.

Gun Control Console

The gun control console (GCC) units, designated GCC 1 and GCC 2, are located adjacent to the COC. Each unit performs the functions of the gun director, fire control computer, and gun captain station normally associated with a fire control system. Each GCC has a TV camera monitor and a B-scan video presentation.

Optical Sighting System

Optical Sighting System Mk 1 has two TV cameras mounted topside. One optical sight, remote optical sight (ROS) 1, is mounted on a stabilized platform, whereas the other, ROS 2, is mounted on and boresighted with the air radar antenna. The air track sight mounted on the antenna thus follows the radar antenna in bearing and elevation. Both optical sights are positioned automatically in response to computer signals or by manual control signals from the gun control consoles. Lens and camera control for the sights are accomplished from their respective GCC unit.

Signal Data Translator

Signal Data Translator is used to convert various analog information to digital form for application to the computer. The data translator also converts digital gun orders (from the computer) to analog signals for gun application.

Digital Computer Mk 152

The Mk 152 is a general-purpose stored-program digital computer. The computer program, stored in computer memory, contains all the instructions and fixed constants needed to solve the fire control problem.

The computer is programmed to perform the track-while-scan (tws) computations required for four surface targets, while at the same time performing computations required to control the AN/SPG-60 air radar for acquiring and tracking an air target.

Motor Generator

Motor Generator converts 440-volt 60-hertz 3-phase ship supply to 115-volt, 400-hertz, 3-phase power for use by the computer.

Radar Set AN/SPG-60

The air track radar (AN/SPG-60) includes a monopulse antenna, a track transmitter, receiver and operating controls, and a display located at the Gun Control Consoles. A TV camera (part of the optical sighting system) is boresighted with the antenna. Operating controls and the display for this camera are located at the GCCs. The air track radar provides the TARTAR missile system with tracking data and continuous wave (cw) target illumination from the cw illumination transmitter.

Radar Set AN/SPQ-9

The AN/SPQ-9 is a high-resolution surface search radar. This track-while-scan set is comprised of a receiver, a driver (frequency converter-multiplier), a transmitter, a radome, and an antenna mounted on a stabilized platform. A separate beacon transmitter-receiver is incorporated in the radar set. The beacon unit is capable of interrogating a radio beacon and receives and decodes the beacon responses.

CW Illuminator

The cw illuminator (cwi) operates in conjunction with the AN/SPG-60 radar. It illuminates the target to provide reflected energy for control of the TARTAR missile. The cwi shares a common antenna with the AN/SPG-60 radar.

SYSTEM CAPABILITIES

Some of the capabilities of the GFCS Mk 86 apply to a particular mod only and are so specified.

Gun Fire Capability

The GFCS Mk 86 is capable of directing, by means of appropriate ballistics software, any caliber gun against any type of target (surface, shore, or air). Using one or more of its primary operating modes (described later in this chapter), the system is very effective against all targets within range of the weapon used.

Engagement Flexibility

The system is capable of simultaneously engaging two targets, while operating in separate modes if required. The mode flexibility and the multitarget track capability permit rapid shifts between targets. Ballistics, which may be different for each target, are computed immediately for the type of ammunition selected.

Missile Control Capability

The GFCS Mk 86 functions with guided missile systems in the control of semiactive homing missiles such as TARTAR. The GFCS tracks and provides continuous wave illumination (cwi) and target data to the missile system while continuing to function as a gun fire control system.

The TARTAR fire control capability of the GFCS Mk 86 enables it to accept AA designation from a number of different sources. The system can interconnect with other digital missile control systems and provide smooth, accurate tracking data by direct intercomputer data link.

Interfacial Capability

The GFCS Mk 86 has a highly flexible interfacial capability. Thus, the system can readily supply and accept analog or digital designation and target data to and from external sources, such as the naval tactical data system (NTDS) or the weapons direction system (WDS). Digital communication in an intercomputer mode permits an essentially instantaneous exchange of target data, grid coordinates, and status conditions. The system may utilize inputs from any one of four target designation transmitters for target acquisition.

OPERATION

Some information which may be helpful in operating the GFCS Mk 86 is contained in this section. Detailed operating instructions are found in the applicable system OP.

Operating Modes

The GFCS Mk 86 has five operating modes and three submodes to carry out its fire mission. System operating modes are discussed in the following paragraphs. The testing mode is not described at this time since its function is maintenance and not operation.

SURFACE RADAR.–The surface radar mode is used primarily in a surface fire mission against enemy ships. Radar is the principal means of surveillance and automatic target tracking. This mode also can be used against shore targets if the terrain permits radar acquisition.

In the surface radar firing mode, targets are located and selected at the control officer console (COC). The high-resolution AN/SPQ-9 surface radar measures the range and true bearing of the target. A video processor is used to translate data from raw video to digital data between the radar and the computer. The video processor also provides digital target position and detection data.

Once a target is acquired, the digital computer track-while-scan routine can maintain simultaneous tracking of up to four selected targets. In the ballistic computation routine, smoothed radar data and appropriate ballistic data are used to compute gun orders and their rates of change. The solutions are fed to the signal data translator where they are converted to synchro signals and transmitted to the gun via the fire control switchboard.

Firing orders and spotting corrections during the firing mission are made from the gun control console (GCC). Splash SPOTTING observations are made on the optical sight monitor or the B-scan of the GCC. The optical sight is pointed by the computer to allow visual target identification and provide splash observation.

SURFACE/SHORE VISUAL.–The visual mode is used against surface targets and in direct shore bombardment fire. When this mode is used, information for the fire mission is obtained by optically tracking targets, using the remote optical sight TV. Accurate target bearing is obtained from the remote optical sight TV. Target bearing and GCC operator estimates of other target data (range, speed, and angle) are used to get a ballistic solution. Radar surveillance and tracking of targets can be performed in this mode, and radar range can be accepted when available. In direct shore bombardment, target height above sea level is entered by the GCC operator.

SHORE INDIRECT.–The indirect shore mode is used against land targets that cannot be picked up with the radar or optical sight system. Target and ownship grid coordinates are set into the computer at the GCC. Ship position is automatically updated by inputs from the ship's compass and the speed sensor. SPOTTING is accomplished by the GCC operator. Automatic compensation of spotting data is made for orientation of the observer-target line (the line from spotter to target).

SHORE BEACON.–The shore beacon mode is identical to the shore indirect mode except that ownship position is determined and maintained by automatic tracking of a radar beacon at known coordinates. This mode produces a more accurate solution than does the shore indirect mode.

AIR ACTION.–In the air action mode, the computer automatically controls the searching for and tracking of air targets. Target data and a view along the boresight axis of the AN/SPG-60 radar are displayed at the gun control consoles.

The air action mode includes three submodes. They are air action radar, air action visual, and air action radar/visual. Acquisition, tracking, and control of gun fire are automatic in the radar submode. In the visual submode, all operations are performed by observation of the TV optics. The visual submode also may be used in counterbattery fire and in quick action against low flying aircraft. The radar/visual submode permits visual tracking in either bearing or elevation, or both, while using radar ranges.

Operating Stations

The entire GFCS Mk 86 is controlled by three (below deck) console operators. The COC operator is responsible for administering the overall fire mission. The COC operator energizes the equipment, establishes the mode of operation for the GFCS, performs radar area surveillance, initiates and monitors radar target tracking, and assigns guns and targets to each gun control console. The COC operator (normally an officer) also monitors the fire status of the guns and releases control of firing to each GCC operator. This transfer is accomplished by direct signal and voice communication.

The GCC operator controls the fire of one or more guns against assigned targets. Both GCC units are identical and are used for the same purpose.

On ships having single gun installations one GCC is omitted.

CLOSE-IN WEAPON SYSTEM (CIWS MK 15) AGFCS

The Close-in Weapon System (CIWS) was developed to provide the fleet with a close range hard defense against antiship cruise missiles, fixed wing aircraft, and surface targets. The system is an automatic fast reaction computer-controlled radar with a rapid fire 20 millimeter (MM) gun. The system has a high kill probability. This highly unitized system is suitable for installation on most ships as a single unit. It permits smaller ships to have a degree of self-protection never before possible.

SYSTEM LAYOUT

The CIWS (fig. 11-7) consists of a weapon group (WG) Mk 16, a local control panel (LCP) Mk 339, and a remote control panel (RCP) Mk 340. A special round of 20 millimeter ammunition will be discussed later in this topic.

The weapon group Mk 16 Mod 1 (fig. 11-8) is composed of fire control radar receiver/servo assembly (radome assembly), 20 mm gun subsystem, mount and train drive assembly, barbette assembly, and an electronics enclosure.

An operator uses the RCP in conjunction with the LCP to monitor and control operations of the system. The radome assembly encloses the search and track radar microwave units (antennas and receiver), antenna drives, mount gyros, and vertical reference unit (VRU).

The gun assembly supports the radome assembly and consists of the M61A1 Gatling gun and its gun drive components, elevation yoke, and ammunition drum and chutes. The mount supports the gun assembly and contains the elevation and train drive assemblies for the gun. The barbette equipment assembly supports the mount train drive platform and encloses the search/track radar transmitter, environmental control group (ECG), gun hydraulics, power supply, and mount power switching and transformer units.

The electronics enclosure contains most of the system's electronics, which are contained on replaceable circuit card assemblies (CCAs). These CCAs are mounted in pull-out drawers located in the electronics enclosure, which is located behind the barbette assembly.

SYSTEM COMPONENTS

A CIWS battery, although self-contained, is made up of many separate units. One of these is located at a site remote from the battery itself. It is the remote control panel (RCP). The RCP is installed in the combat information center (CIC) and provides controls and indicators for remote tactical operation of the battery. The RCP parallels the operational command and control functions of the local control panel (LCP) and exercises priority when the remote operation is selected.

The LCP is the major control station of the CIWS and is the only panel from which threat criteria and engagement data can be entered into the weapon control group computer.

When the RCP experiences a casualty the LCP is used as the primary control for the

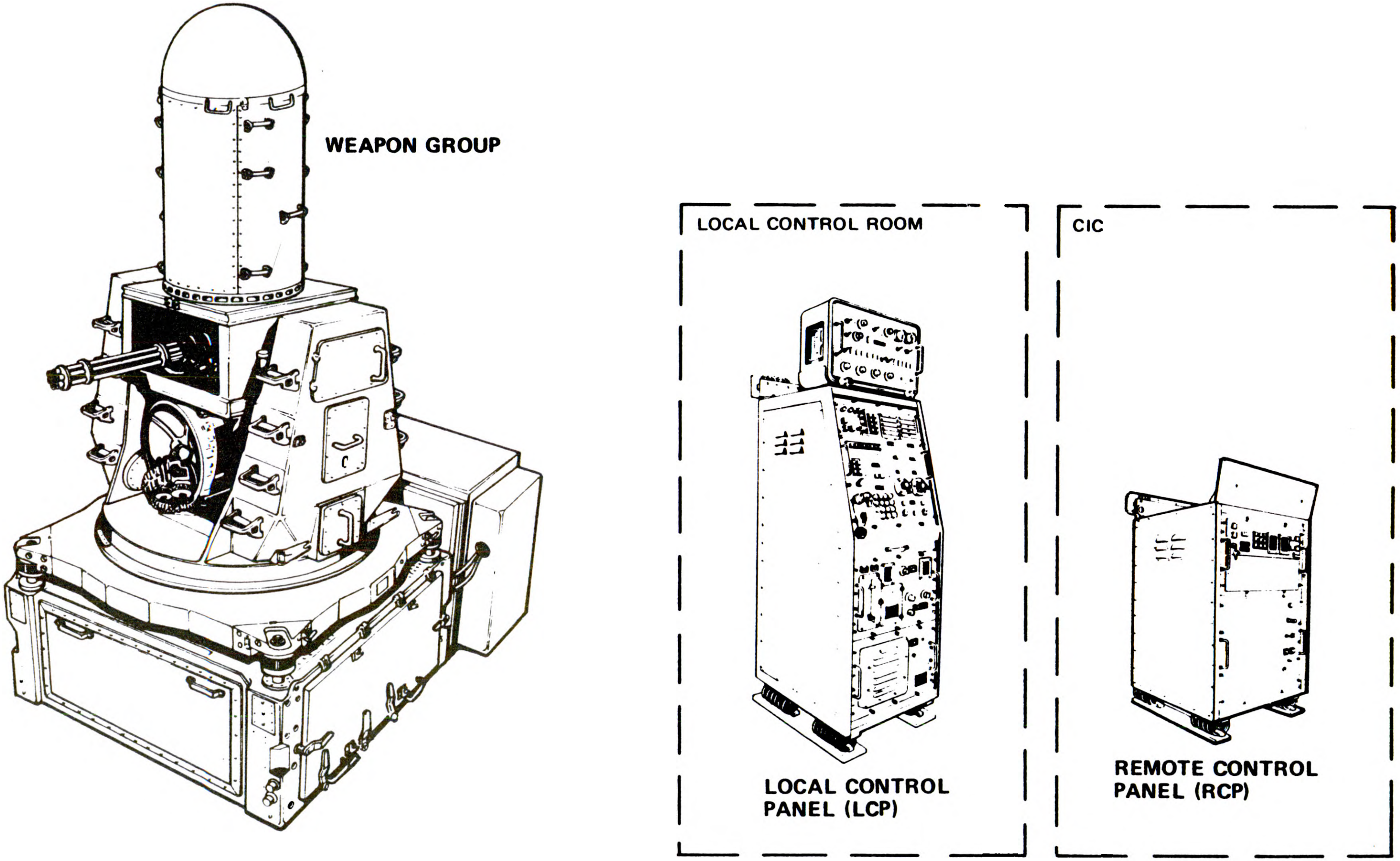

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Figure 11-7.—CIWS system layout.

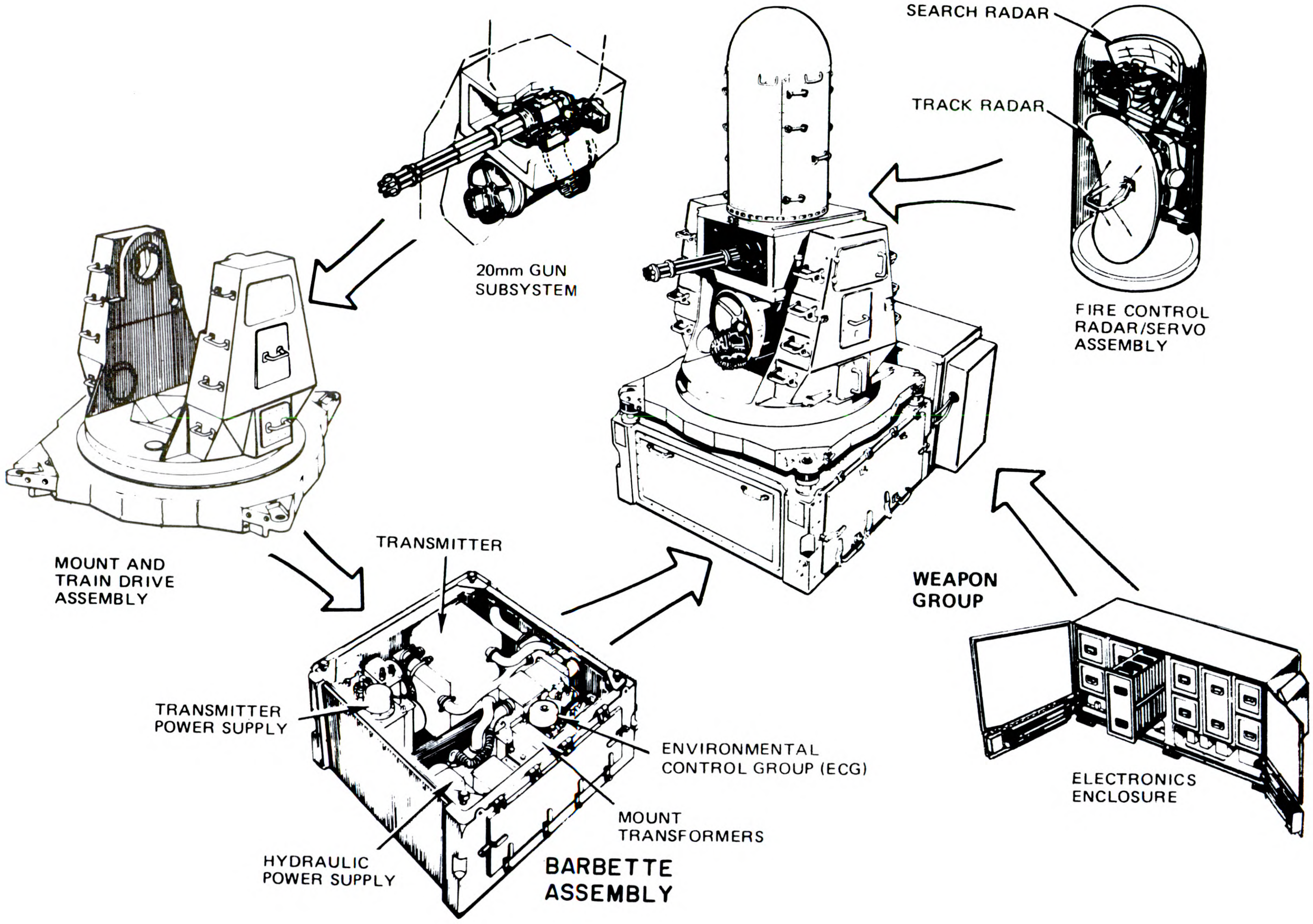

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Figure 11-8.—Weapon group MK16.

system. The LCP is also used as the maintenance control panel, as the RCP has no maintenance capability. Using the controls and indicators and, where appropriate, common and peculiar support equipment, an operator can conduct operability tests, fault isolation, and maintenance operations.

The radar servo assembly of the weapon group (fig. 11-8) contains an electronic spotter subsystem which utilizes a coherent pulse doppler radar for automatic spotting. The radar shares the same transmitter and receiver but uses separate search and track antennas mounted within the radome. The search and track servos perform separate functions which provide stabilized search antenna drive and track antenna drive. The search assembly controls search antenna rotation, provides a stabilized platform for the antenna, provides traverse position information concerning the search radar beam, provides platform traverse rate information (ship turning rate) for search, and traverse feedback to assist mount slew during the changeover from search to track functions. The track assembly provides limited track antenna angle search (15° train, +7.5° to -10° elevation) during acquisition, keeps the radar boresight on target during track, and provides antenna position (elevation and train) and rate (elevation, azimuth, and roll) information for use in gun aiming.

A general-purpose digital computer, the electronics circuits to interface the computer with other system elements, and the necessary software consisting of operational and test programs, are all housed in the weapon control group.

The following functions are accomplished by the weapon control group:

- System Mode Control.–Through selection of appropriate operational subprograms
- Radiation Control.–Superstructure and emission control (EMCOM) sectors
- Search Processing.–Threat evaluation, false alarm sorting, jamming and detection
- Handover and Acquisition.–Mount position orders, signal processor assignment, target range and range rate designation, and antenna scan orders
- Fire Control Solution.–Lead angle, coordinate transformation, digital filtering, compensation, and aim bias correction
- Operability Testing.–For automated portions of tests
- Instrumentation.–Data to magnetic tape (for test purpose only)
- LCP/RCP Displays.

A power supply and control group (PSCG) controls distribution of ship's power within the system including distribution to transformer, transformer-rectifier, inverter, and power supply units which develop the special power required by various subsystems.

The environmental control group (ECG) consists of a closed-loop air conditioning system that dehumidifies intake air, provides waveguide pressurization, and maintains the necessary environmental control within various subsystems. The ECG uses sea water to cool the deionized water coolant. The coolant in turn cools the air within the weapons system housing (electronics enclosure), and cools the transmitter klystron, dummy load, transmitter modulator and high voltage power supply.

Built-in test equipment is located throughout the system to provide on-line monitoring of critical functions, a centralized system for remote test point selection and access, and external test points for connection of common support equipment (CSE) and peculiar support equipment (PSE). The test control unit (TCU) is the centralized system controlled by the weapon control group (WCG) or the test point selector unit (TPSU) for call-up and readout of internal test points located on test interface modules (TIMS) which are found throughout the system.

The mount assembly supports the gun and radome assembly and contains the gun elevation drive mechanism. The associated train drive platform contains the mount train drive mechanism. The high performance drive systems can track accurately at rates up to 100° per second in train and 86° per second in elevation.

The M61A1 Gatling gun is an electrically controlled, hydraulically driven, 3000 round per minute, 6 barrel, low dispersion, 20 millimeter gun equipped with a 980 round magazine and a closed loop ammunition feed system. (Empty cases are recycled back into the magazine.) The gun incorporates a positive cease fire function designed so that, when firing ceases, no live rounds are left in the chamber. Electrical elevation and train limits are provided for protection against accidental firing into the ship's superstructure or areas that would endanger personnel. An indication is provided at the LCP when the gun is in a clear zone and can fire. An indication is also provided at the LCP and RCP when the gun is firing.

A special round of ammunition (Mk 149) (fig. 11-9) was developed especially for the CIWS. It includes a projectile and discarding plastic cover (sabot). The 1090 grain projectile uses depleted uranium as the penetrator material and glass phenolic for the windscreen.

SYSTEM OPERATING MODES

Figure 11-10 illustrates the various system operating modes and their interrelationships. The system may be placed in each of the modes manually from the LCP. If the system is in AAW Auto, and remote designation is enabled, it will automatically accept the designated target. In all modes, when the GUN SAFE/GUN ARMED switch on the controlling panel (LCP or RCP) is in the GUN SAFE position, it interrupts all trigger and fire voltage relay coil circuits so that the gun cannot be fired accidentally.

When the system is in the BATTERY OFF mode, the LCP BATTERY OFF switch/indicator is activated. In this mode, all power is removed from the weapon group except ECG power, which is controlled independently by its own circuit breaker. Normally, this circuit breaker is closed, and the ECG operates continuously in the BATTERY OFF mode. Either automatic or manual sequencing down to the BATTERY OFF mode

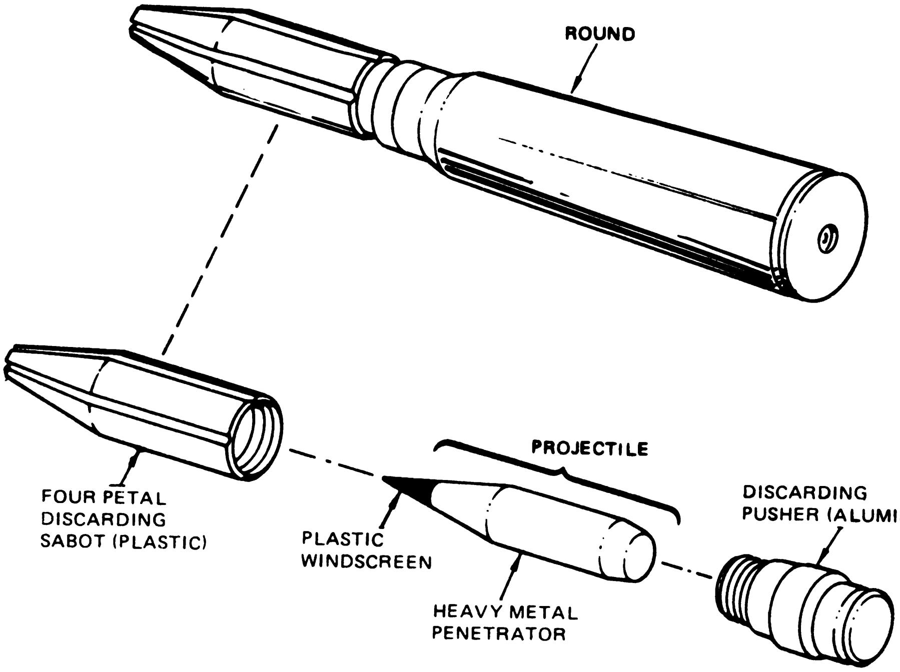
ROUND
PROJECTILE
DISCARDING PUSHER (ALUMINUM)
FOUR PETAL DISCARDING SABOT (PLASTIC)
PLASTIC WINDSCREEN
HEAVY METAL PENETRATOR

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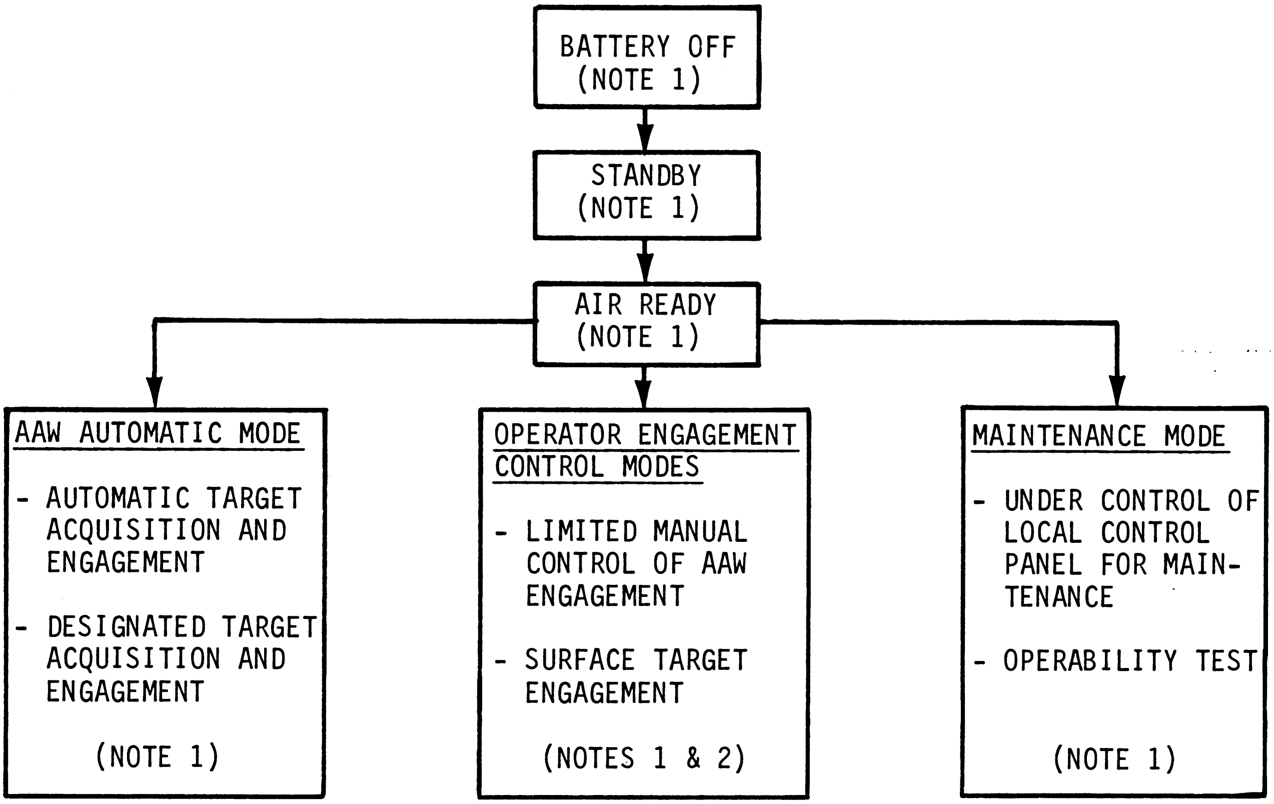
Figure 11-9.—Specialized round.


BATTERY OFF (NOTE 1)
STANDBY (NOTE 1)
AIR READY (NOTE 1)
AAW AUTOMATIC MODE
- AUTOMATIC TARGET ACQUISITION AND ENGAGEMENT
- DESIGNATED TARGET ACQUISITION AND ENGAGEMENT
(NOTE 1)
OPERATOR ENGAGEMENT CONTROL MODES
- LIMITED MANUAL CONTROL OF AAW ENGAGEMENT
- SURFACE TARGET ENGAGEMENT
(NOTES 1 & 2)
MAINTENANCE MODE
- UNDER CONTROL OF LOCAL CONTROL PANEL FOR MAINTENANCE
- OPERABILITY TEST
(NOTE 1)

NOTES: 1. MODE ENTERED MANUALLY
2. OPERATOR ENGAGEMENT CONTROL MODE IS AAW MANUAL OR SURFACE

166.252

Figure 11-10.—CIWS modes of operation.

is possible from any other mode of operation. On the LCP, turnoff and light off is initiated by LCP operator action only.

When the system is brought up to the STANDBY mode of operation, low level power is supplied for transmitter warm-up and spin up for the vertical reference unit (VRU). The system is safe and the radar is silent. This mode is the lowest level of operation permitted in routine steaming (condition III). A submode (ELX POWER) energizes power to the electronics enclosure circuits when performance of certain maintenance operations in STANDBY is desired.

As soon as the AIR READY mode is selected, all mechanical functions necessary to permit immediate operation are activated, and the system is in rf silence. In this mode the LCP operator can enter data into the weapon control group using a keyboard. Remote designation of targets can be accepted from this mode.

The AAW AUTOMATIC and AAW MANUAL modes of operation are essentially the same. Operator control is limited to preset conditions and to hold-fire or break engagement override functions. If no target is under engagement, the system can accept a target designation if remote designation is enabled from external sources and, on engagement termination, it can return to normal search. In AAW AUTOMATIC, weapon firing is automatic, if the gun is pre-armed, as soon as all criteria are met, but in AAW MANUAL the LCP or RCP operator has to initiate firing.

When the CIWS is in the AIR READY mode or higher, pressing the REMOTE DESIG switch/indicator on the LCP or RCP enables the system to accept a designated target and command change to the AAW AUTOMATIC mode for engagement. The operator must arm the gun. After the engagement, the system returns to the mode from which designation occurred.

In the SURFACE mode, the system accepts and responds to commands from a TDT for target designation and firing control. Hold-fire control and burst size control (60 or 100 round bursts) are retained at the LCP.

The MAINTENANCE mode for the system is controlled from the LCP for the purpose of conducting scheduled and unscheduled maintenance. This mode is made up of the following four separate submodes.

1. OPR TEST.–This particular submode is utilized to check the operability of the system and is controlled from the LCP. The test consists of different computer controlled tests of the rf search. The rf track, and the search antenna stabilization are portions of the daily system operability test (SOT).
2. XMTR TEST.–Initiation and control of transmitter testing from the LCP is performed when this test is selected.
3. SEARCH ONLY.–In this submode, system operations are limited to radar search. Target designation, handover, track, and the like, are precluded in this submode.
4. AIM CALIB.–The preaction calibration mode is used to remove residual gun aiming bias without the presence of a target, by firing a burst of projectiles, and is completed within 15 seconds after being ordered from the LCP.

END TEST.–This particular switch is used to remove the system from the MAINTENANCE test currently in progress.

OPERATIONAL SEQUENCE

The system has been designed to operate within the primary defense perimeter as determined by the effective range of other defensive weapons systems. The normal operational mode is automatic search with a manual override. The system maintains a continuous search through 360° in train minus superstructure cut out, and from -5° to +4.5° in respect to horizontal plane in elevation. Above the elevation search limit, another source of designation must be used to acquire a threatening target for the system.

When a target is detected, it is evaluated in terms of range, range rate, and sector location. If the engagement criteria for a hostile threat are met, the battery is designated automatically by the system computer. When open-fire range is reached, the gun starts firing on a continuous basis using a closed loop aim correction system until WCG analysis of target track data indicates that the target has been destroyed.

This method of spotting employs a range gate placed over the target that permits its use as a reference point to track the centeroid (center of mass) of outgoing Mk 149 projectiles. The angular error between the target and projectile is monitored and the system continuously decreases angular error by applying corrections to the mount's servos and power drives.

At the 3000 round-per-minute firing rate of the gun system, many checks and corrections of the aiming point are made which provide a very high probability of a hit on the target. A kill is determined by the system when target return indicates that range rate has slowed drastically or the return signal amplitude shows a large change in magnitude. The system then returns to search mode of operation and awaits the next target.

HARPOON WEAPON SYSTEM

The HARPOON weapon system is an all-weather, over-the-horizon, antiship weapon system that detects and destroys enemy surface targets. Even though the HARPOON weapon system differs radically in design from the other gun fire control systems described in this chapter, it is still within the area of responsibility of the FTG rating. The HARPOON is a missile that is designed to engage surface ships. It is launched from a shipboard canister or launcher and seeks out and destroys a selected surface target.

The HARPOON weapon system (HWS) (fig. 11-11) is composed of the HARPOON ship

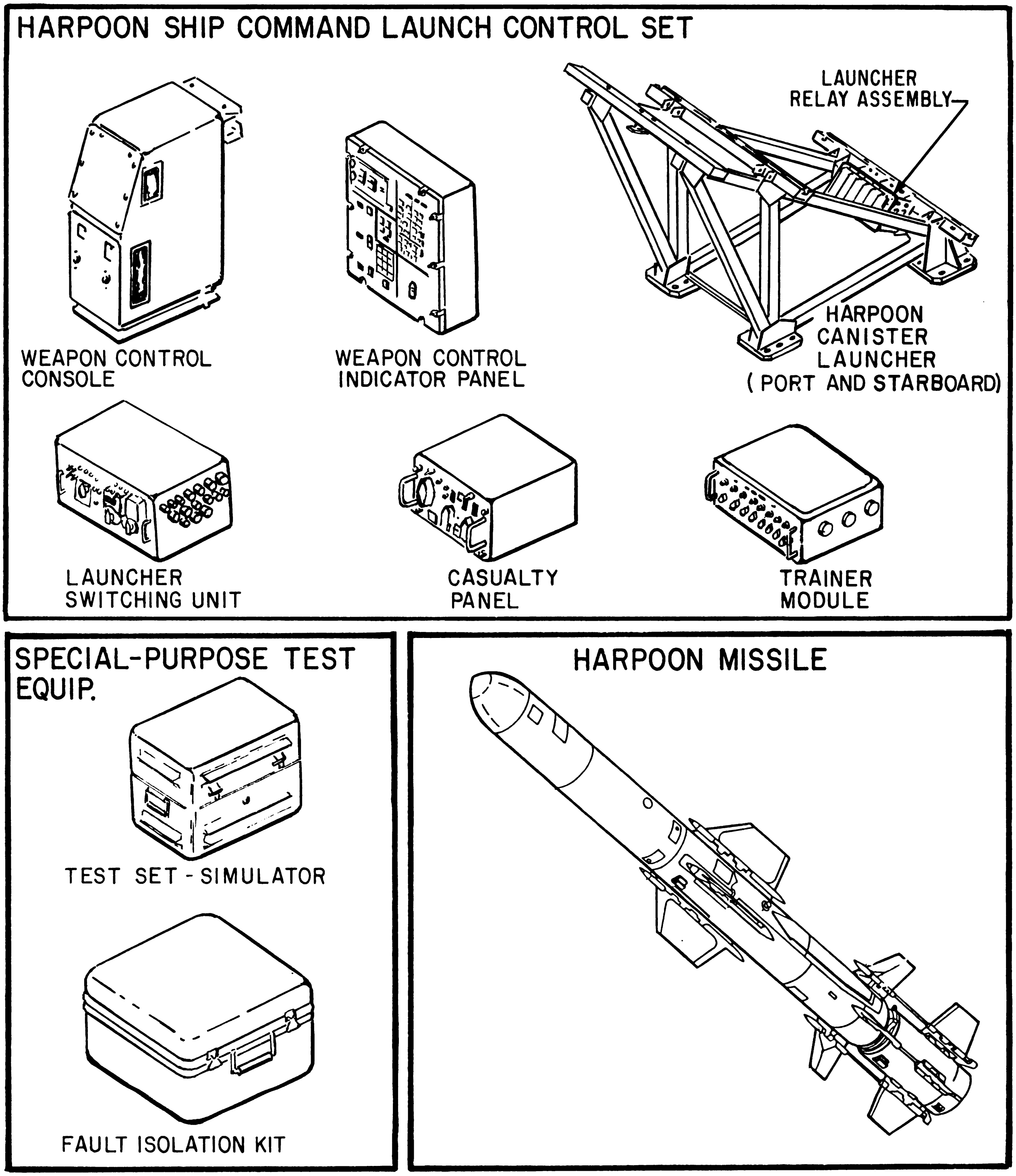


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Figure 11-11.—Harpoon weapon system (HWS).

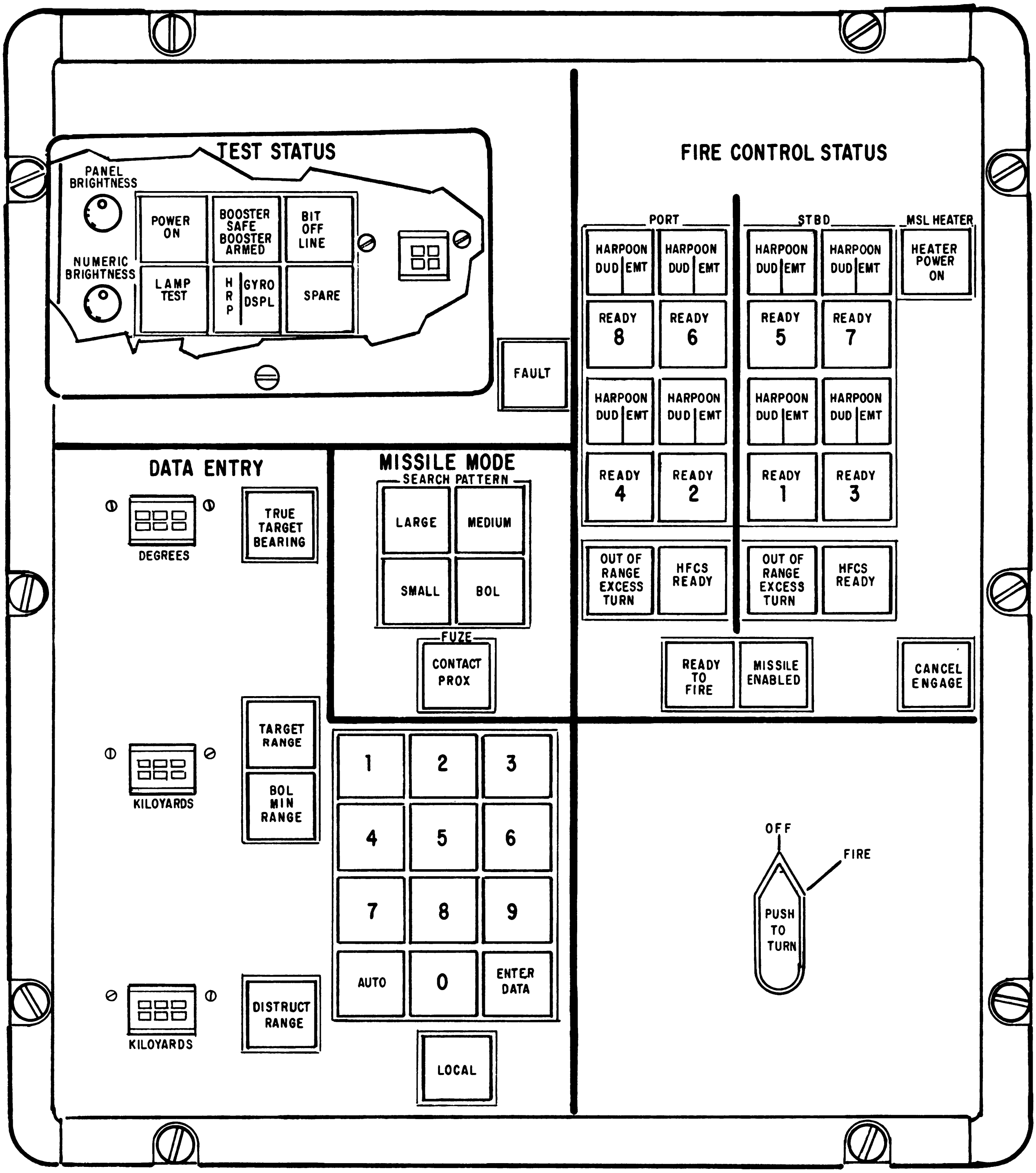

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Figure 11-12.—Weapon control indicator panel.

command and launch control set (HSCLCS), the HARPOON missile, and the special purpose test equipment.

HARPOON SHIP COMMAND AND LAUNCH CONTROL SET (HSCLCS)

The HSCLCS provides control, computation, monitoring, and built-in test functions for the HARPOON weapon system. It is interfaced with existing (ownship) weapon systems, (radars, sonar, NTDS, etc.) and utilizes their target data. The HSCLCS provides all prelaunch functions necessary for warm-up, aiming, and firing of the missile. Its functions are to apply ship's power to the missiles, select the modes of operation, control launch sequence, supply the missile with target data, and display HSCLCS and missile status. The HSCLCS (fig. 11-11A) consists of a weapon control console, weapon control indicator panel, missile canister launcher, launcher switching unit, casualty panel, trainer module, and components required to integrate the HSCLCS with other shipboard equipment. The HSCLCS command and control is accomplished in the combat information center (CIC) from the Weapon Control Indicator Panel.

Weapon Control Console (WCC)

The WCC is located in an unattended equipment room of the HWS or in CIC. It houses a digital computer that computes missile orders derived from target (range and bearing) and ownship parameters (roll, pitch, speed, and heading). These orders are sent to the HARPOON missile and instruct the missile as to how to make its attack on the enemy ship.

Data conversion units are also housed in the WCC. These units have digital-to-analog and analog-to-digital converters to interface the HWS with other ship systems (radars, sonar, NTDS, etc.)

Weapon Control Indicator Panel

The weapon control indicator panel (WCIP), shown in figure 11-12, contains controls and indicators required to operate the HWS. This panel, located in the surface area of CIC and manned by an operator, is the command and control station of the HWS. All information needed by the HWS is entered through the WCIP and all information necessary to show the status of the HWS is displayed by the WCIP. Tests on the HWS are also conducted from the WCIP.

Inputs and controls to the WCIP are target data, ownship data, missile selection, missile search patterns, and firing of the HARPOON missile. Target data is entered either automatically by NTDS or manually by the operator.

Displays for the proper control of the HWS, such as the status of the HARPOON missiles, range and bearing parameters of the target, and indications that the input data was inserted correctly by the operator, provide the operator with the information necessary to operate the HWS.

HARPOON Canister Launcher

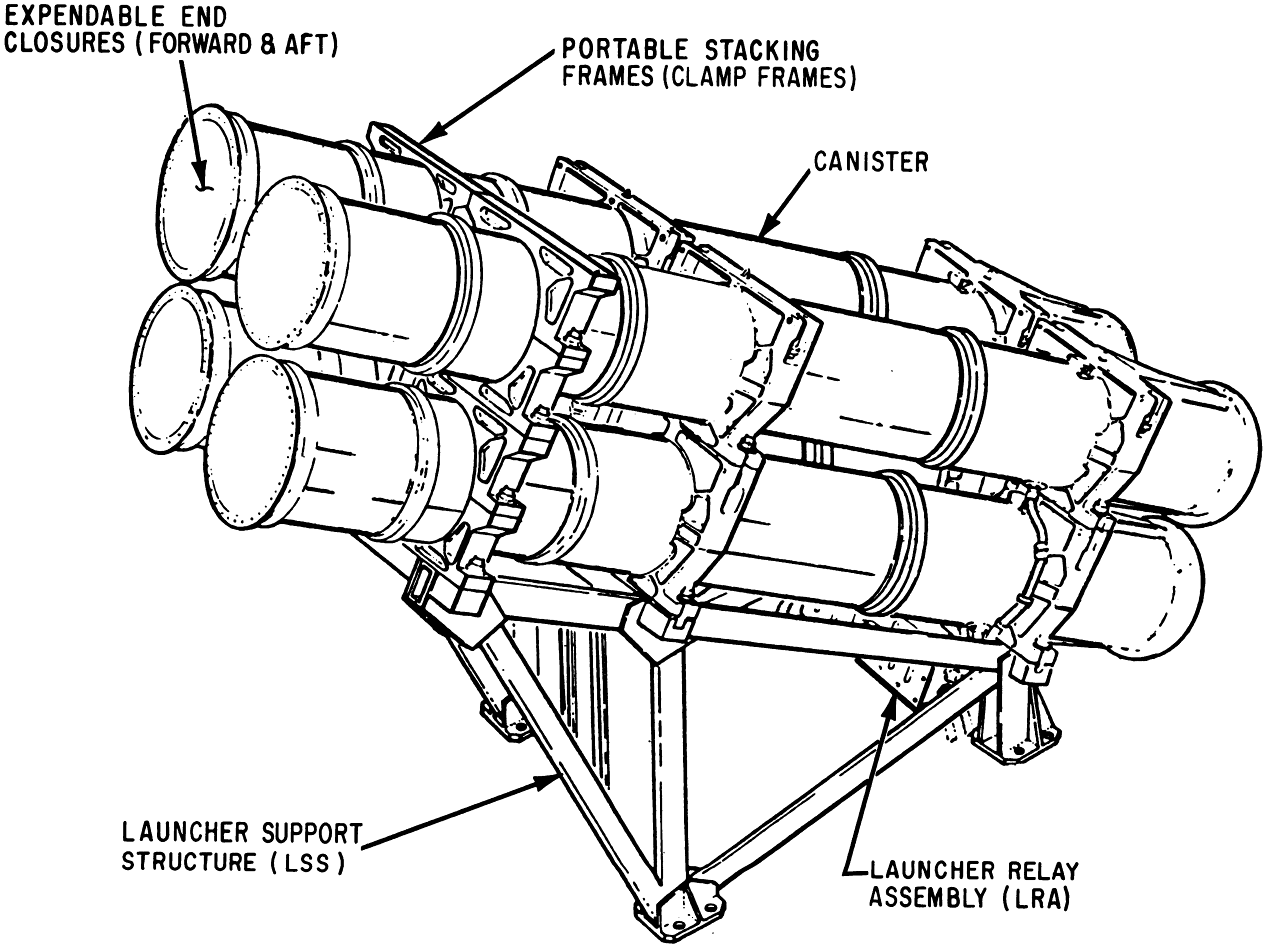
The HARPOON canister launcher (HCL) (fig. 11-13) consists of a launcher support structure, a launcher relay assembly, and canisters. The launcher support structure is bolted to the deck of the ship and supports the canisters. Each canister contains one HARPOON missile, launch rails, and a restraining mechanism to hold the missile in place until firing. The launcher relay assembly houses the interconnect cables that connect the HARPOON missiles to the rest of the HWS.

The HCLS are shown in figure 11-14 as they appear on ships. As you can see, the missiles are fired up and over the ship. The missiles are automatically programmed to turn after launch to the target bearing.

TARTAR and ASROC launchers may also be used to launch HARPOON missiles.

Launcher Switching Unit

The launcher switching unit (LSU) (fig. 11-15) provides the capability of selecting either


EXPENDABLE END CLOSURES (FORWARD & AFT)
PORTABLE STACKING FRAMES (CLAMP FRAMES)
CANISTER
LAUNCHER SUPPORT STRUCTURE (LSS)
LAUNCHER RELAY ASSEMBLY (LRA)

166.255

Figure 11-13.—HARPOON canister launcher with canisters installed.

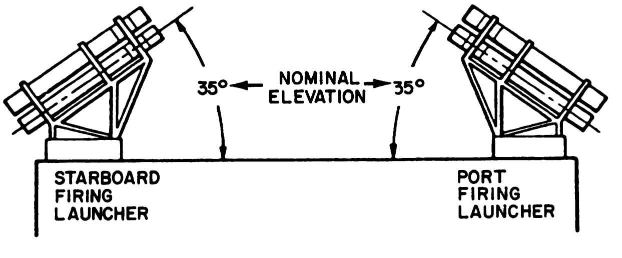


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Figure 11-14.—HARPOON canister launchers mounted aboard ship.

the port or starboard canister launcher and can route prelaunch data into selected missiles. The LSU contains firing interlocks required to fire a single missile or a series of missiles in ripple (one after the other) sequence. The LSU also has the capability of selecting the training mode and providing required synchro and discrete (digital) data to the HSCLCS for off-line testing.

Casualty Panel

The casualty panel (CP) (fig. 11-16) is used to launch HARPOON missiles when missiles cannot be launched using the WCC. The CP

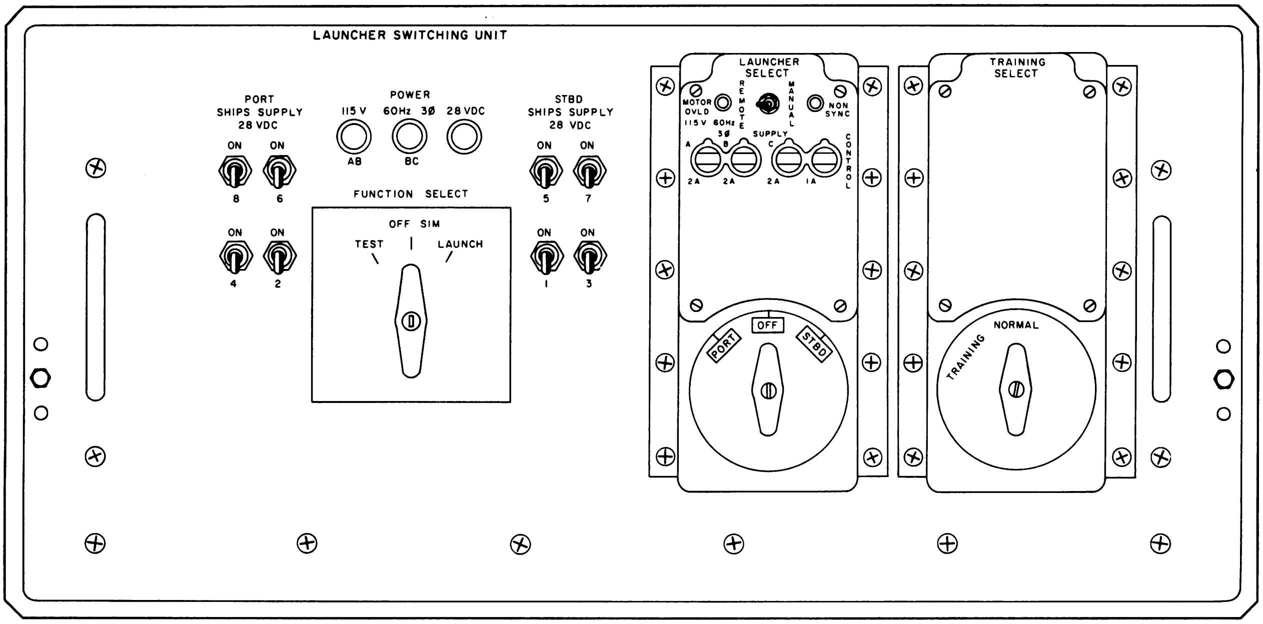

Figure 11-15.—Launcher switching unit. 166.257

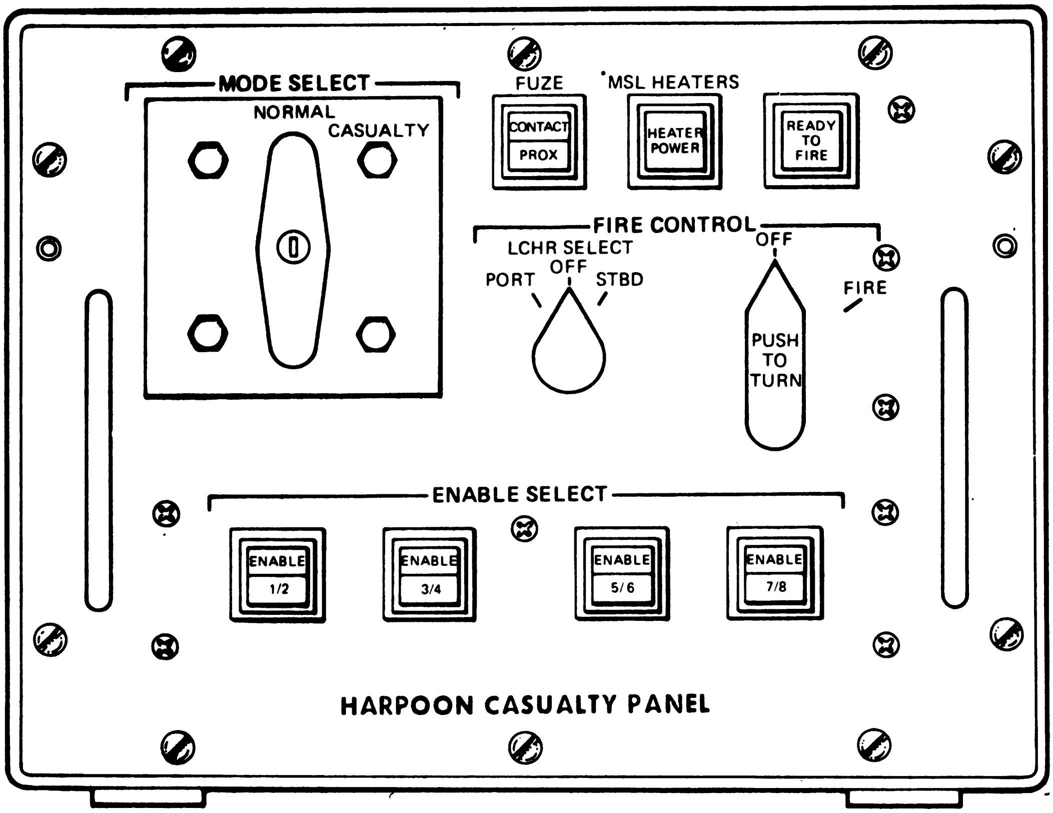

Figure 11-16.—Casualty panel. 166.258

interfaces directly with the LSU and permits launch without the WCC or support systems inputs, such as the ship's gyro inputs.

Trainer Module

The trainer module (TM) (fig. 11-17) allows training of WCIP operators on the HSCLCS. This is done by the TM simulating the status signals that come from the missile canisters (empty, HARPOON missile, or dud). This information from the TM is sent to the WCIP.

HARPOON MISSILE

The HARPOON missile (fig. 11-18) is an advanced surface-to-surface (antiship) guided missile that features over-the-horizon range, active guidance, low-level cruising, and counter-countermeasures. The missile consists of five sections—booster, boattail, sustainer, warhead, and guidance. The missile is either installed in a canister before it is loaded on the ship, or loaded directly into ASROC or TARTAR launchers. Therefore, it requires no assembly or maintenance.

The booster section contains a solid-propellant rocket motor that lifts off and brings the HARPOON missile up to cruising speed. At this time, the booster is separated from the missile.

The boattail section contains the flight control fins for guiding (steering) the missile throughout its flight.

The sustainer section contains a turbojet and fuel to maintain the HARPOON missile in flight after the booster has separated.

The warhead section, as the name implies, carries a high explosive for the HARPOON missile.

The guidance section contains a seeker, an altimeter, and a midcourse guidance unit. The seeker is a radar used for the terminal guidance of the missile to the target. If the target (ship) attempts to jam the missile's radar, the missile tracks the jamming (this is called counter-countermeasures). The altimeter is needed because of the low-level cruise trajectory of the missile (just above the water). The midcourse guidance unit (a computer) is used to guide the HARPOON missile towards the target until the seeker finds and tracks the target. Then, the seeker guides the missile the rest of the way to the target.

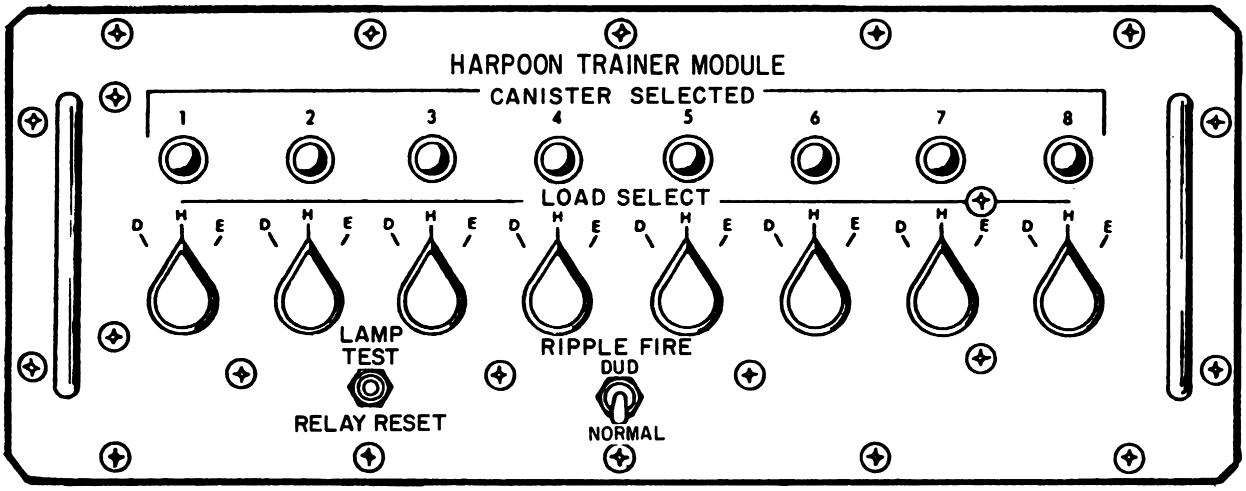

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Figure 11-17.—Trainer module.

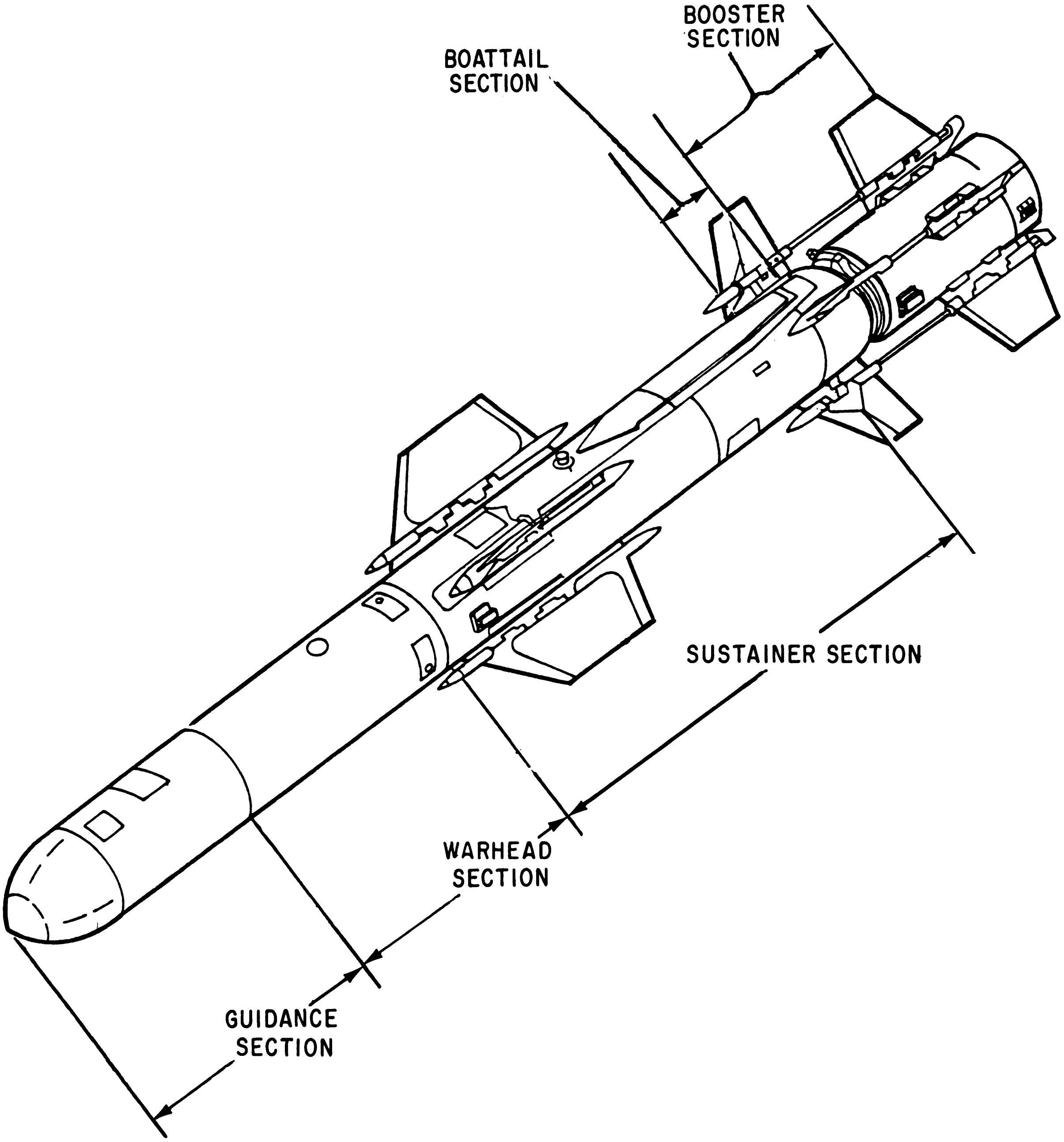

Figure 11-18.—Surface Attack Guided Missile (HARPOON Missile).

HARPOON Missile Flight Profile

The HARPOON missile flies a unique trajectory (fig. 11-19) from launch until it reaches the target. The missile is launched from ownship by power from the booster. When the appropriate velocity is reached, the booster separates, the warhead is armed, and the turbojet takes over. Next, the HARPOON missile goes into a dive and levels off just over the water. This is accomplished by the guidance section. The low-level cruise trajectory makes it

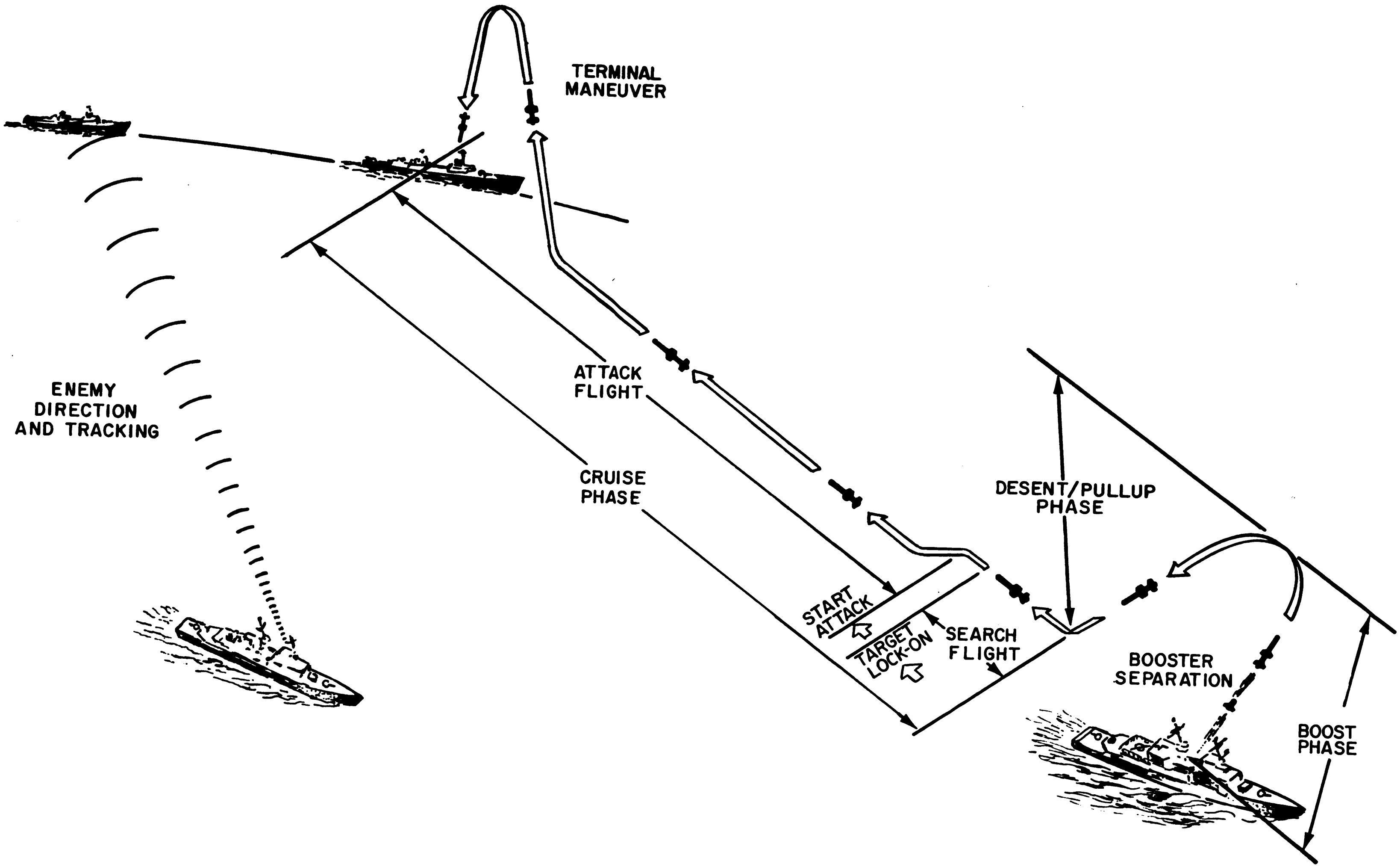

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Figure 11-19.—HARPOON missile flight profile.

difficult for the target ship to detect or shoot down the incoming HARPOON missile.

Once the HARPOON missile has leveled off, it begins to search for the target with the seeker radar in the guidance section with the search parameters inserted by the operator before launch. Soon, the missile finds and locks on the target, and the missile begins its attack flight.

Just before the HARPOON missile reaches the target, the guidance section causes it to rise up and then dive on the target, giving the missile a better destruction factor.

SPECIAL-PURPOSE TEST EQUIPMENT

The special purpose test equipment consists of the test set-simulator (fig. 11-20) and the fault isolation kit (fig. 11-21). The test set simulator provides the HWS with missile load simulations and missile-to-HSCLCS data exchange for testing, fault isolation, and training. The fault isolation kit consists of test cards (circuit boards) used for troubleshooting the WCC components. The fault isolation kit assists in rapid isolation of defective printed-circuit cards in the WCC.

SUMMARY

This chapter has presented some of the developments in the field of gun fire control that you may encounter. This field is in a state of constant change, improving the equipment already in use and keeping the Navy at the vanguard of today's technology. Keeping abreast of developments will be of benefit to both yourself and the Navv.

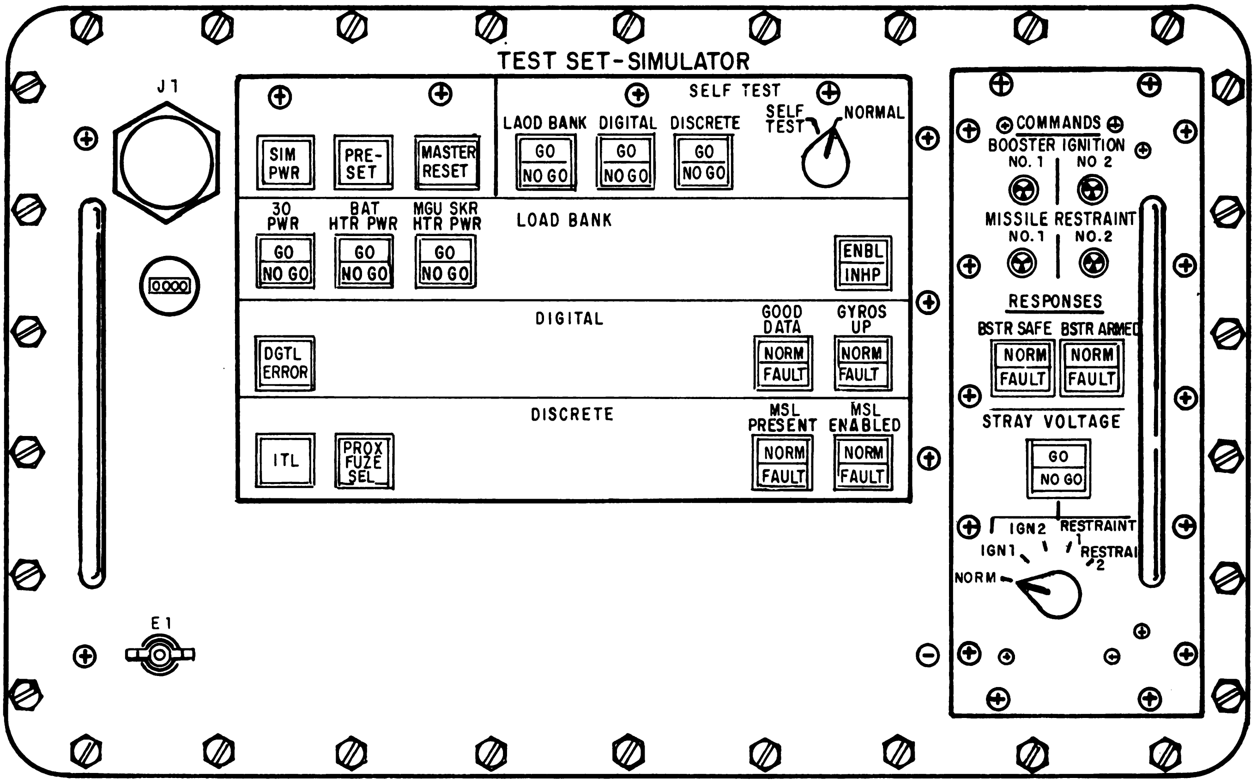

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Figure 11-20.—Test set-simulator.

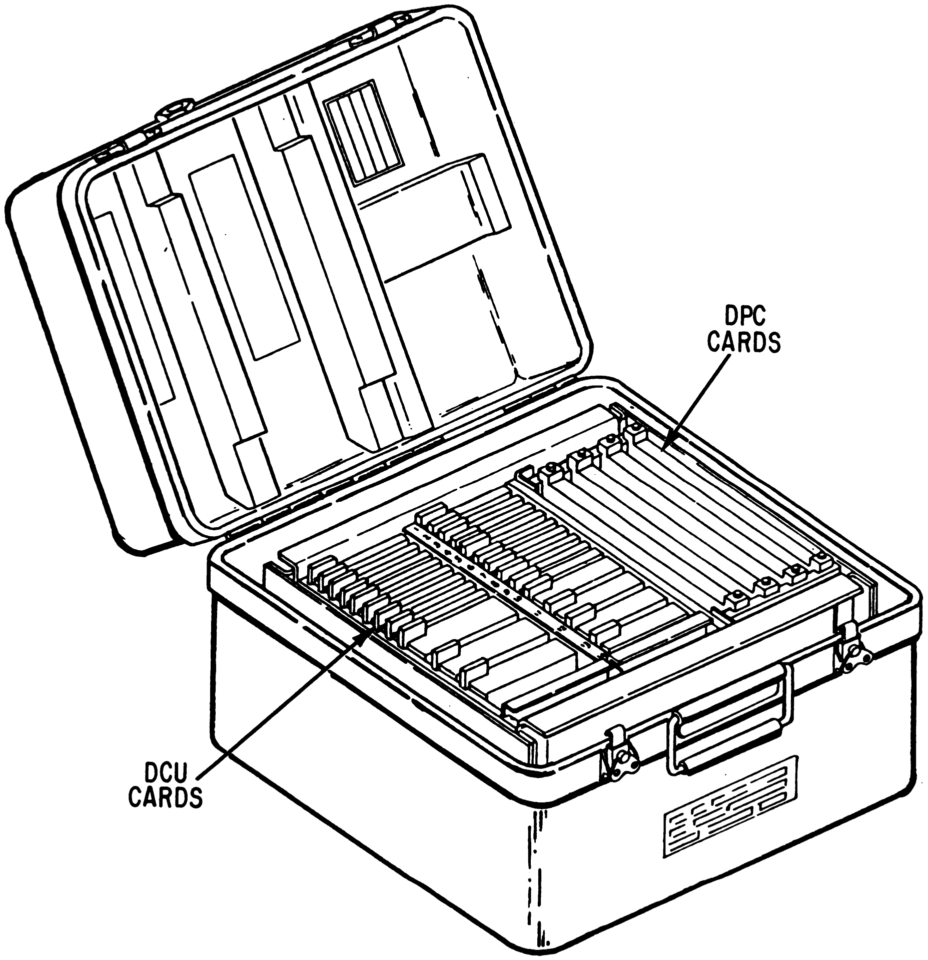

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Figure 11-21.—Fault isolation kit.

CHAPTER 12

BATTERY ALIGNMENT

Battery alignment is the process of adjusting all the elements of a weapon system (in a gun battery this includes the director, sights, radar, computer, stable element, and the gun mount sights and barrel) to common reference points, lines, and planes, and maintaining them in this relationship. Figure 12-1 shows the elements of a gun fire control system that require battery alignment.

Battery alignment is a critical factor in the fighting effectiveness of any combat ship. Without proper battery alignment, the projectiles that are fired will not impact "on target," despite a high rate of efficiency by the crew, high-power radar and optical equipment, speedy fire control computation, or a high rate of fire. Maintenance of accurate battery alignment is of primary concern to you as a fire control technician. Beginning when the ship is under construction and lasting as long as it remains in commission, battery alignment is a continuing process. Although some battery

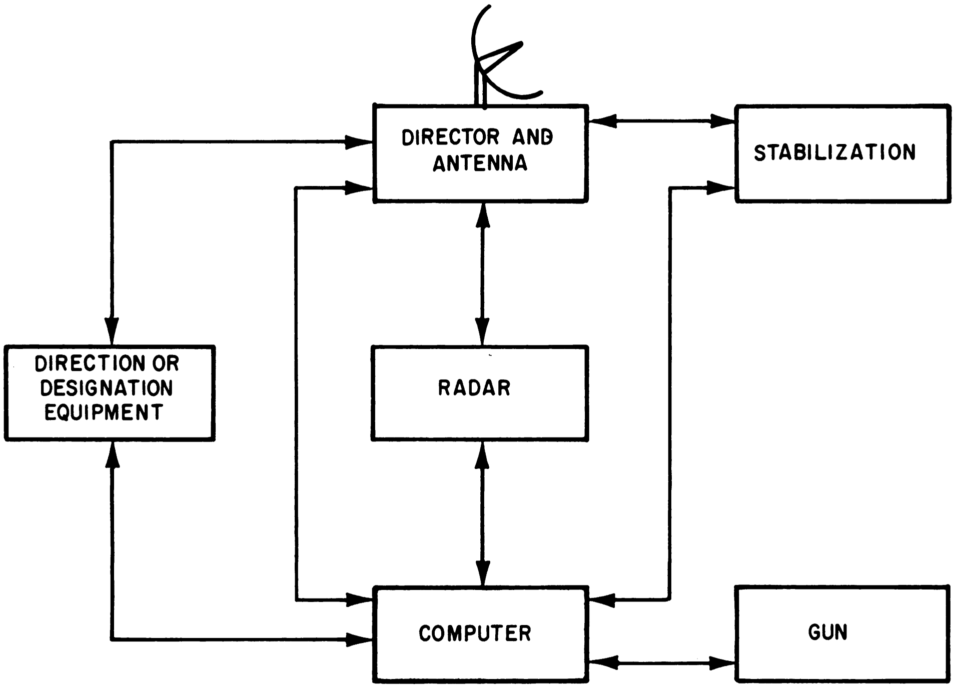

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Figure 12-1.—Elements of a GFCS that require battery alignment.

alignment operations are performed as infrequently as once every 2 years, some operations (such as transmission checks) are done every day.

PURPOSE OF BATTERY ALIGNMENT

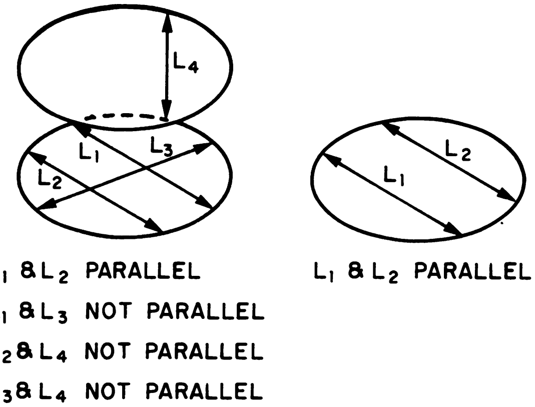
The purpose of battery alignment is to adjust the guns of the battery and the associated fire control equipment so that the lines of sight of the optical equipment, the beam axes of the radar antennas, and the bore axes of the guns in the battery are all parallel when the following conditions prevail:

- Dials are matched and all gun mounts are in automatic
- No parallax corrections are introduced
- No ballistic corrections are introduced
- No rates are introduced

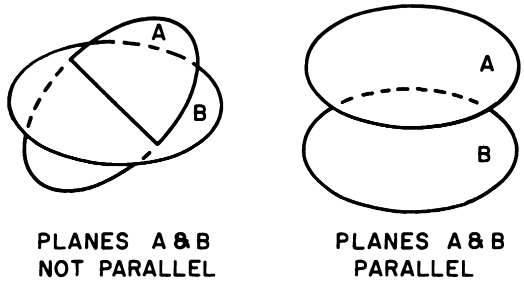
In a correctly aligned system, all associated gun bores, beam axes, and lines of sight remain parallel under these conditions throughout all operating motions, and all instrument dials and automatic control equipment measure these motions correctly with respect to the proper reference point, line, or plane.

CONCEPTS OF ALIGNMENT

Alignment is based on the concepts of parallel lines, parallel planes, and a geometric coordinate system. Parallel lines (fig. 12-2A) are defined as lines in the same plane that do not intersect. Parallel planes (fig. 12-2B) are defined as planes that do not intersect. A geometric coordinate system provides a method for determining the position of a point, line, curve, or plane in a space of given dimensions (reference frame). Examples of geometric coordinate systems are the polar and the rectangular coordinate systems, shown in figure 12-3.


L_4
L_1
L_3
L_2
L_2
L_1
L_1 & L_2 PARALLEL
L_1 & L_3 NOT PARALLEL
L_2 & L_4 NOT PARALLEL
L_3 & L_4 NOT PARALLEL
L_1 & L_2 PARALLEL

A. PARALLEL LINES



B. PARALLEL PLANES

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Figure 12-2.—Typical Examples of Parallel Lines and Planes.

Ultimately, the alignment of parallel lines, parallel planes, and coordinate systems is used to establish a pointing line for each piece of equipment in the ship's combat system. The line representing the direction in which a piece of equipment is pointing is referred to as the pointing line of that equipment. As previously indicated, the pointing line may be the bore axis of a gun, the line of sight of a director, or the propagation axis of a radar beam. Accurate alignment is not possible unless the pointing line is precisely determined.

Frame of Reference

The reference point, reference direction, and reference plane form a geometric structure

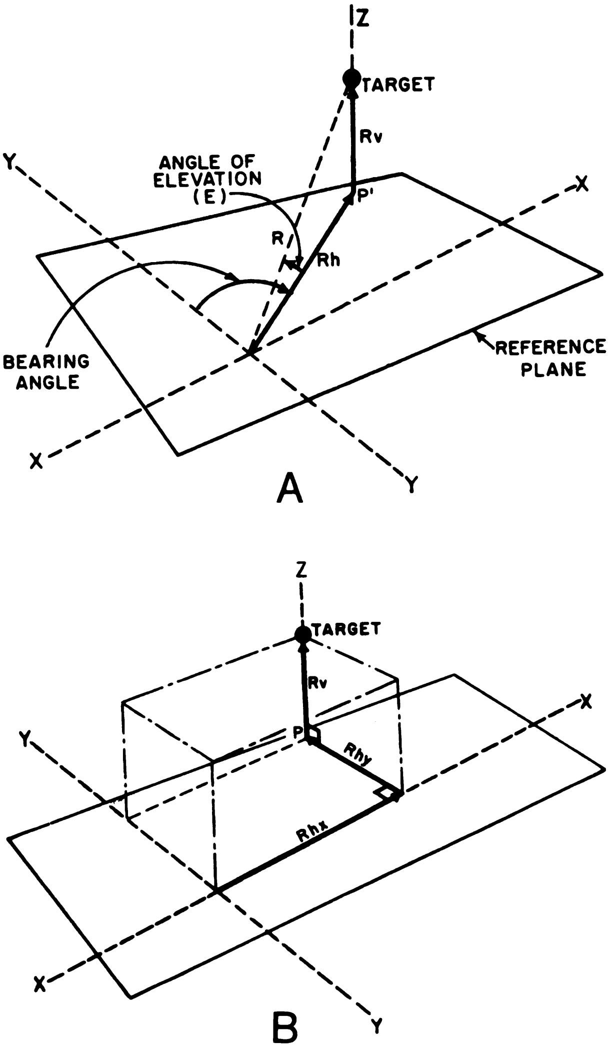

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Figure 12-3.—Three-dimensional Rectangular Coordinate System.

called a reference frame. In the complete reference frame, directions are specified by two angles (train and elevation) measured about the reference point.

A geometric measurement is based on a definite and complete set of geometric references. To permit clear and accurate definition of target position, a definite point on the ship (such as a director) is selected as the starting point for the measurement. As a reference point, a director center of rotation is selected arbitrarily, and the selection is due primarily to the fact that the director has interface with all the major equipment of a battery. Once the reference point is determined, it becomes a part of any measurement made from it, and must be clearly specified before subsequent measurements have any meaning.

Once the reference point is selected, a reference direction is established from which train angles are measured. Train angles are measured about the reference point, beginning at the reference direction, as shown in figure 12-4. In naval combat systems, the ship centerline, pointing in the direction of the bow, is used as the reference direction.

Angles expressing direction cannot be described unless a means is available for specifying the plane in which the angle is to be measured. This plane (fig. 12-5) is referred to as the reference plane and may be any plane convenient for use. The horizontal plane is one of the most commonly used reference planes, due to the ease of using a spirit level or similar device to determine the plane. In naval combat systems, the reference plane is parallel to the reference element (director) roller path. Whichever plane is selected for reference, it must be clearly specified before subsequent measurements are of any significance. When the

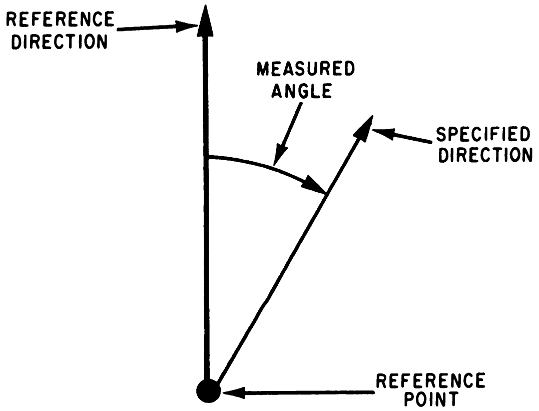

Figure 12-4.—Measurement of an angle from a reference direction.

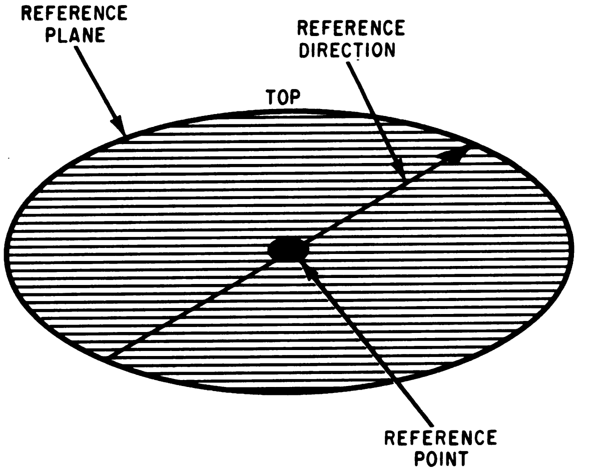

Figure 12-5.—Typical Reference plane.

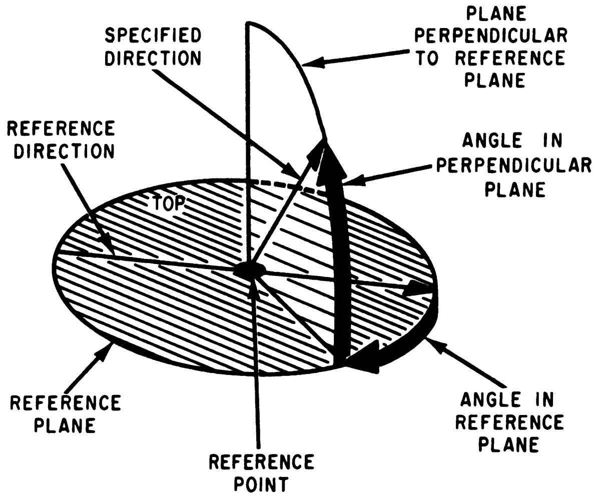

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Figure 12-6.—Representation of a complete reference frame.

reference plane is used, a means must be established to denote the top of the plane to express the angle correctly. Train angles are measured clockwise from the reference direction on the top of the plane.

The elevation angle is in a plane perpendicular to the horizontal reference plane and is measured from the reference plane, as shown in figure 12-6. The concept of a reference frame is important in the expression of a direction and the problems related to alignment. It must be remembered that the reference point is a definite point aboard ship, and the reference plane and reference direction have a definite orientation in respect to the reference point.

TYPES OF BATTERY ALIGNMENT

The battery alignment of a ship is accomplished by two distinct procedures: original alignment (drydock alignment) and alignment afloat. Original alignment is the initial alignment made in a fire control and weapons system at the time of original construction and installation. This is a very elaborate and highly accurate series of operations, done in drydock by the shipbuilder or outfitting yard. Original alignment is also performed whenever a new or modified major weapons system is installed. A check of this alignment is made whenever the ship is in drydock for repairs.

Battery alignment in drydock is usually performed by shipyard ordnance mechanics. You will not be directly involved with the work that is performed by these personnel. For this reason, shipyard battery alignment is not discussed in this chapter. If you desire information, consult the latest revision of Alignment of Ordnance Installations Aboard Ship (OP 762).

Alignment afloat refers to alignment operations performed while the ship is waterborne (in port or underway). Alignment afloat requires standards of accuracy just as high as those of original alignment. The main difference is that alignment afloat is performed by the weapons department personnel, with equipment available on the ship.

ALIGNMENT ERRORS AND THEIR SOURCES

In alignment operations, errors and discrepancies can be traced back to three sources:

1. Human error (observation error)

2. Lost motion

3. Instrument error (mechanical error)

Human Error

Human error is caused by factors such as the failure or inability of operating or maintenance personnel to match index marks or graduations; the tendency to misread, or to read with limited accuracy, scale indications; the failure to line target points up exactly with the reticules or crosshair intersections of optical equipment; and the like. This is not necessarily caused by personnel incompetence. Incompetence or carelessness, however, may cause this type of error to increase to serious proportions. Even the sharpest-eyed, most skillful, and most conscientious person has limitations. To keep adjustments and observations as free of human error as possible under the usual conditions aboard ship, working personnel should take the following precautions:

1. Each observation or measurement should be made as carefully as possible. This requires that the operation itself be carefully prepared and performed. It is important also to use care in reading dials (to count the graduations accurately) and to look at the dial squarely to avoid apparent displacement (parallax effect) of the index or pointer and the graduations.

2. Critical measurements should be taken two or more times. The value to be recorded is the mean (average) of these.

Lost Motion

Lost motion is normally caused by the wear and deterioration of parts through either use or lack of use. The term applies to looseness or slackness in linkages of all kinds, whether caused by the faulty or sloppy engagement of gears, excess end play of the shafting, or weakening or failure of the springs. A mechanism may, due to any of a number of causes, bind or stick in some ranges of its operation, while it has lost motion in others. A minimal amount of lost motion, like a minimal amount of human error, is, in most mechanisms, impossible to avoid. But, as required during repair work, lost motion must be taken up by the resetting of reusable parts and the replacement of worn parts.

In certain operations, maintenance personnel can virtually eliminate the effect of lost motion (but not lost motion itself) by approaching each critical observation or reading from a given direction. When doing this, if you overshoot, begin again and approach the desired value from the same direction. But, if you are measuring lost motion or actual instrument error itself, you approach first from one direction and then the other, taking a series of readings and averaging them to ascertain the values you seek.

Instrument Error

Instrument error (often called mechanical error) is caused by some kind of incorrect setting or relationship in the equipment. It may be caused by incorrect adjustment of a part, wear, weakening of a spring, warping of a shaft, or any number of other causes. In electrical or electronic equipment, such errors may also be caused by a malfunction. As distinguished from lost motion, instrument error is generally consistent in direction and magnitude. When combined with the effects of human error and lost motion, this characteristic may be obscured.

Note that these three main types of errors do not register separately; they are nearly always present in some degree. The observations and readings you get include the effects of all three. The effects may be either additive, increasing the net error, or subtractive, partially cancelling out and reducing the net error.

BATTERY ALIGNMENT AFLOAT

Because a ship's hull is a flexible structure, it is subject to small but significant changes in shape, induced by varying forces, when it is moved from the drydock to the afloat environment. These changes in hull shape can cause appreciable changes in the alignment of the ship's weapon systems. For this reason, alignment work done in drydock is only a preliminary step in obtaining the alignment that is required when a ship is afloat. The work required to produce the final afloat alignment can be performed with greater ease and accuracy than would be possible if the drydock alignment had not been done at all.

When a combat ship is constructed, roller paths (fig. 12-7) are placed on the ship's structure. Typical placements are shown in figure 12-8. The roller paths are secured to the deck and machined so as to be as parallel (that is, in parallel planes) as possible. Next, the elements of the weapon system are mounted on the roller paths (fig. 12-9). Now, there is a reference plane (called the deck plane) as a point from which to work or make adjustments.

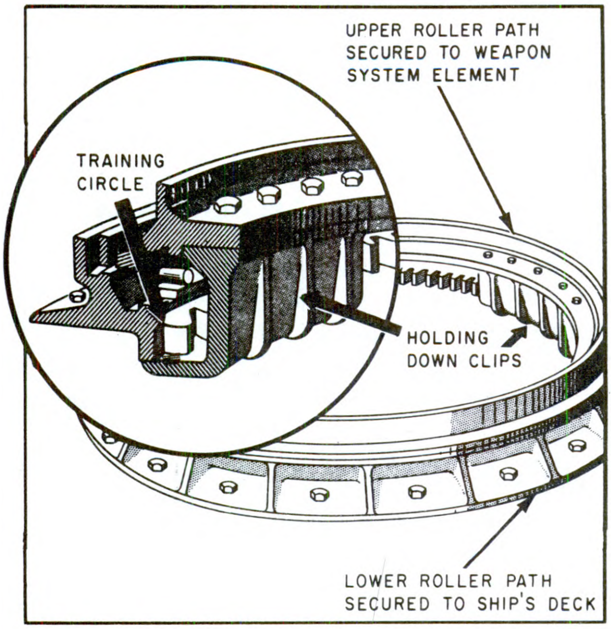
UPPER ROLLER PATH SECURED TO WEAPON SYSTEM ELEMENT
TRAINING CIRCLE
HOLDING DOWN CLIPS
LOWER ROLLER PATH SECURED TO SHIP'S DECK

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Figure 12-7.—Roller path.

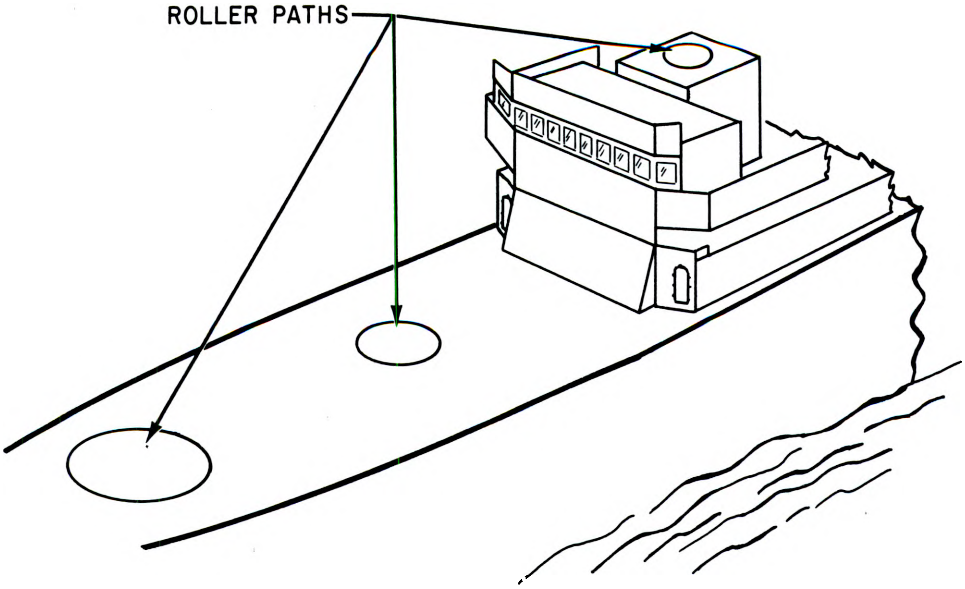

Figure 12-8.—Roller paths are machined until all planes are parallel.

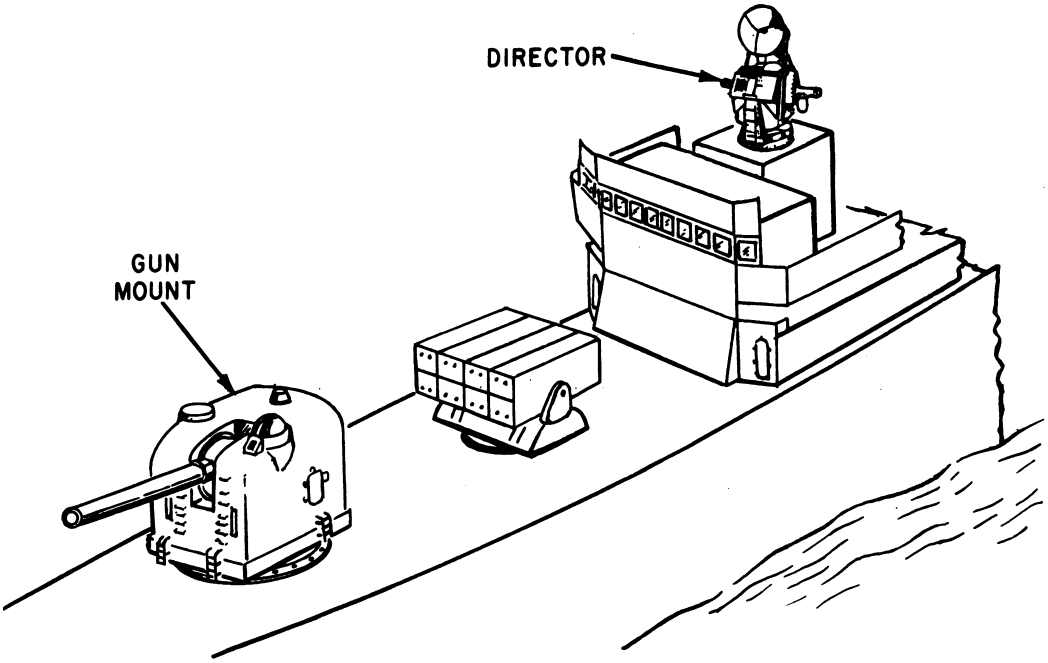

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Figure 12-9.—The director and gun mount are mounted on roller paths.

The next step is to reference all the elements straight ahead toward the ship's bow (000° relative bearing). Now, a reference line exists from which to measure train angles.

The last step is to adjust the elevation of all elements so that they are all looking out at 00° elevation and the lines of sight are parallel. This, then, establishes a reference from which to measure elevation angles.

Accurate measurement of train and elevation angles by all elements of a weapon system is basically what a drydock alignment accomplishes. But, as mentioned earlier, when the ship is launched and waterborne, the hull changes in shape. When the hull changes in shape, the roller paths may no longer be in the same plane. This causes misalignment of the elements of a weapon system in both train and elevation.

The elements can be adjusted to compensate for hull distortion or other sources of misalignment, such as lost motion, instrument error, or human error. This is where you, as a Fire Control Technician come into the picture. Let us now consider the tools and procedures available for maintaining an accurate battery alignment afloat.

REFERENCE ELEMENT

Once the ship is waterborne, there is no sure way of telling if the roller paths of the elements are as level as they were in drydock. The ship is pitching and rolling even in the calmest of waters. Therefore, one element of the weapon system is selected as the reference element (normally a fire control director). All other elements (gun mounts, search radars, and other fire control directors) are then adjusted to the reference element so that their roller path, train, and elevation readings agree with those of the reference element.

ALIGNMENT EQUIPMENT

Alignment equipment are the tools used by shipboard personnel to align the system elements. These consist of the tram bar and tram blocks, bench marks, alignment sights, gunner's quadrants, and clinometers. Alignment equipment normally used in drydock alignment are not discussed in this RTM. If you desire more information, refer to OP 762, Theory Of Combat System Alignment (the latest revision).

Tram Bar And Tram Blocks

A tram bar is a device used to set an element to an exact position. It is used to determine the distance between two tram blocks which are fastened to the element. One block is fastened to the rotating structure of the element; one block is fastened to the fixed structure of the element (fig. 12-10). As illustrated, the tram bar is used to ensure the correct positioning of the movable block. Before continuing let us more closely examine the tram bar.

There are two types of tram bars, a rigid type and a telescopic type. The rigid type is of fixed length and does not allow for error. The telescoping feature of the telescopic type makes it more convenient and safer to use. For this reason, this is the one we describe. Both, however, accomplish the same purpose.

The telescoping tram bar (fig. 12-11A) consists of two parts, one bar sliding within the other. The parts have a small movement with respect to each other and are extended by an internal spring. A scribe mark on the inner part is visible through an opening in the outer part.

Engraved on the edges of the opening is a graduated scale which runs on each side of a zero mark. When the inner scribe mark and the outer zero mark are in line, the tram bar is the correct length. As shown in figure 12-11B, a gage that is furnished with the instrument is used to check that the zero line and scribe mark match when the length is correct. Now that you have some concept as to what a tram bar is, consider once more the blocks.

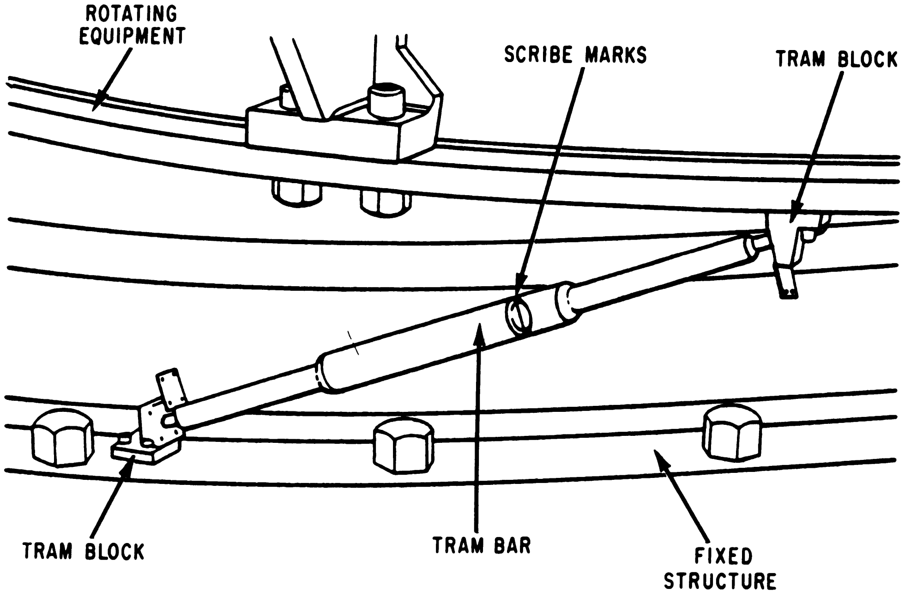

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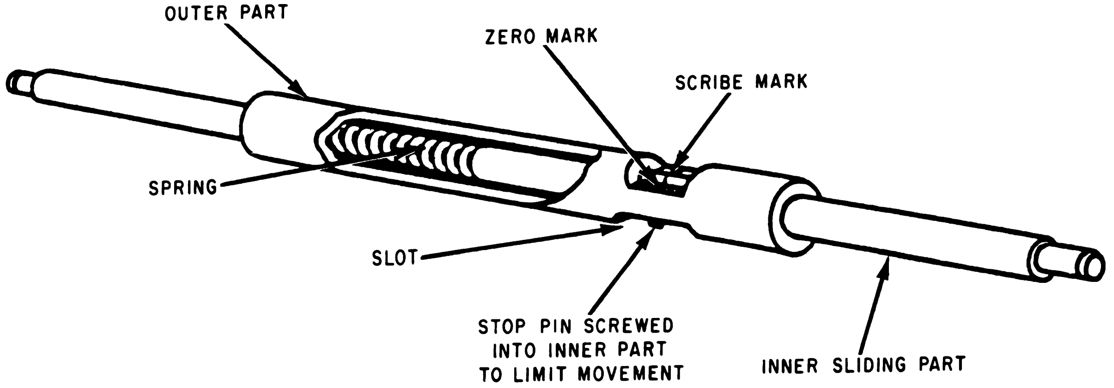
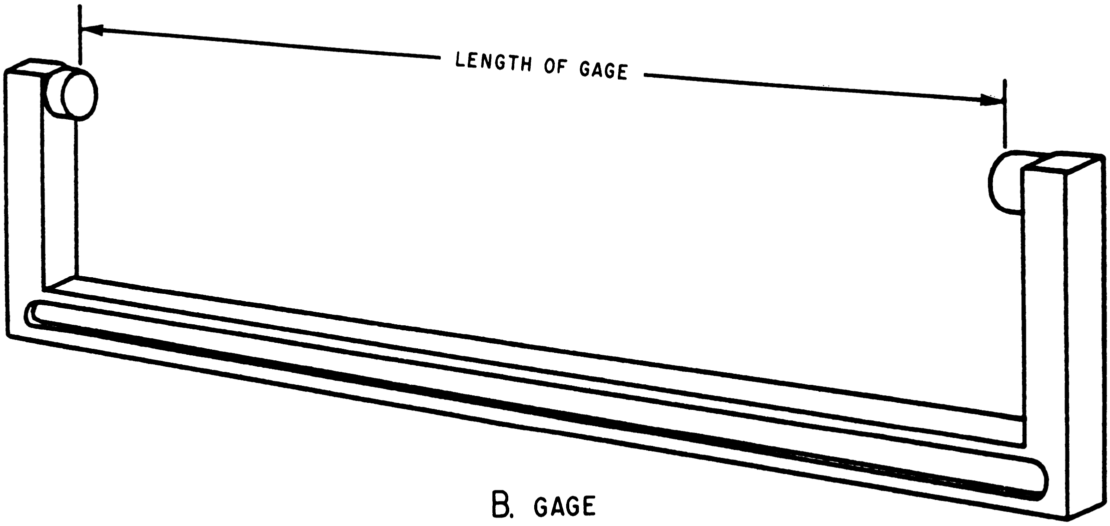
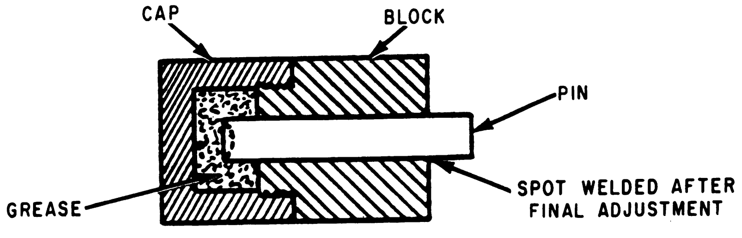
Figure 12-10.—Tram bar and tram blocks.



A. TELESCOPING TRAM BAR



B. GAGE



C. TRAM BLOCK AND PROTECTIVE COVER

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Figure 12-11.—Telescoping tram bar and related equipment.

The blocks (fig. 12-11C) are provided with pins having cupped ends that fit the rounded ends of the bar. One block has a fixed pin, while the other has a movable pin. After the blocks are welded in place on the element, the movable pin can be adjusted so that the scribe mark and tram bar zero line match exactly when the dials of the element are at some even reading. The movable pin is then tackwelded in place. To protect the ends of the pins from damage and corrosion when the pins are not in use, the pin ends (fig. 12-11C) are covered with grease-filled caps.

Tramming operations (fig. 12-10) should be performed with great care if injury to personnel or damage to the equipment is to be avoided. The power drives should not be used unless absolutely necessary. Position the equipment to the approximate tram position and insert the bar with the heavier end down. The bar should not be held in place while the tram blocks are moving with respect to each other; however, should this be necessary, the holding should be done only while the blocks are moving away from each other.

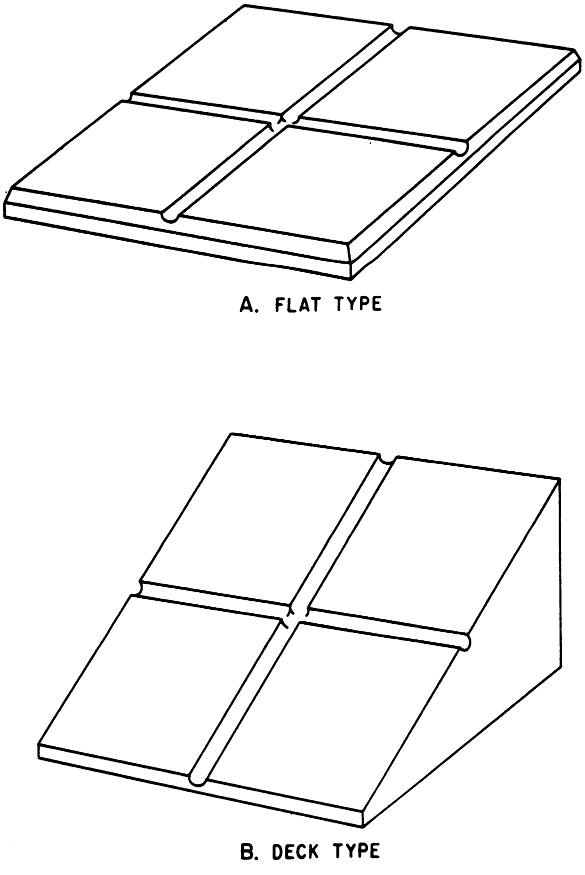

Figure 12-12.—A typical bench mark.

Bench Marks

A bench mark (fig. 12-12) is a small metal plate containing an engraved cross. The plate is either brazed or welded to some rigid portion of the ship's structure at a position where it can be sighted on with the reference element (director). The bench mark may be engraved on a flat plate for bulkhead mounting or on a block with an inclined surface so that the mark is clearly visible on the ship's deck.

A bench mark is a reference mark used in alignment to establish the angular relationships (elevation and train) of an element's line of sight to the ship's structure. When an element is sighted at its bench mark, its dial readings should agree with recorded values. If there is disagreement, alignment of the element is necessary.

Alignment Sights

An alignment sight is an optical device used in establishing the pointing line of a piece of equipment. The pointing line may be the bore axis of a gun, the propagation axis of a radar beam, or some other similar line. Accurate alignment is not possible unless the pointing line is accurately determined.

Determination of a pointing line for some equipment poses a problem, unless special means are used. For example, no problems exist when the pointing line of an element is the los of a telescope, as in a director. In this case, looking through the telescope reveals the exact pointing line. The pointing line can be accurately positioned on a desired target simply by sighting the intersection of the telescope crosshairs on the target.

Determining the pointing line of some elements, however, is not as simple. A gun mount, for example, would pose certain problems. There is no practical way of merely looking through the barrel and determining the exact pointing line. This problem can, however, be solved by mounting a telescope in the gun barrel, and then taking accurate measurements to ensure that the los of the telescope is parallel to the longitudinal axis of the barrel. The telescope's los now represents the pointing line of the gun barrel for alignment purposes. A telescope or other sighting device of this nature used to determine the pointing line of an element is referred to as an alignment sight.

Some alignment sights are installed for temporary use. They are used for alignment and then removed from the element. Others are permanently installed and remain as part of the element.

One type of alignment sight is a boresight (fig. 12-13), which is used to establish the bore axis of a gun. Most boresights are provided with mounting surfaces that fit accurately into the gun bore. The boresight los is aligned precisely with the mounting surfaces when the instrument is inserted in the gun bore. At this time the los is in exact alignment with the gun bore axis.

The boresight is used to boresight the gun and to align the gun to the reference element. The boresight contains all the required optical equipment and mounts in the gun breech. When inserted in the gun breech, the boresight carries two tapered bearing rings that automatically center the assembly in the gun breech. In this way, the boresight los is caused to coincide with the bore axis of the gun.

The alignment of a radar beam is accomplished by temporarily mounting a telescope or by using a fixed, self-contained telescope mounted on the radar antenna dish. In alignment using fixed, self-contained optics (fig. 12-14), the telescope is permanently mounted on a machined surface and accurately positioned so that the telescope's los is parallel to the required pointing axis of the antenna dish. Actual alignment is accomplished by mechanical movement of the antenna dish which causes its pointing axis to parallel the telescope's los.

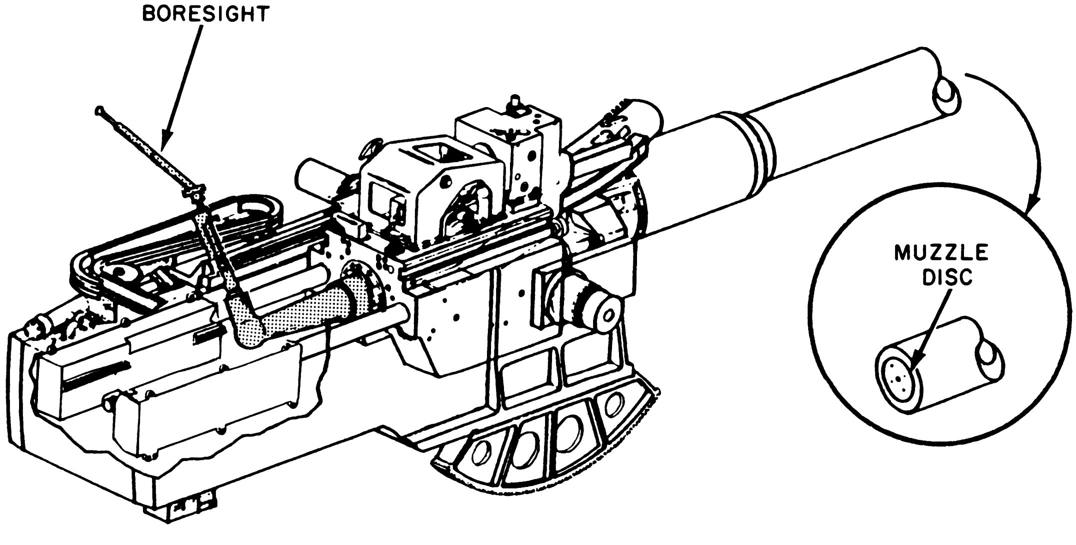

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Figure 12-13.—Boresight in 5-inch 54-caliber gun.

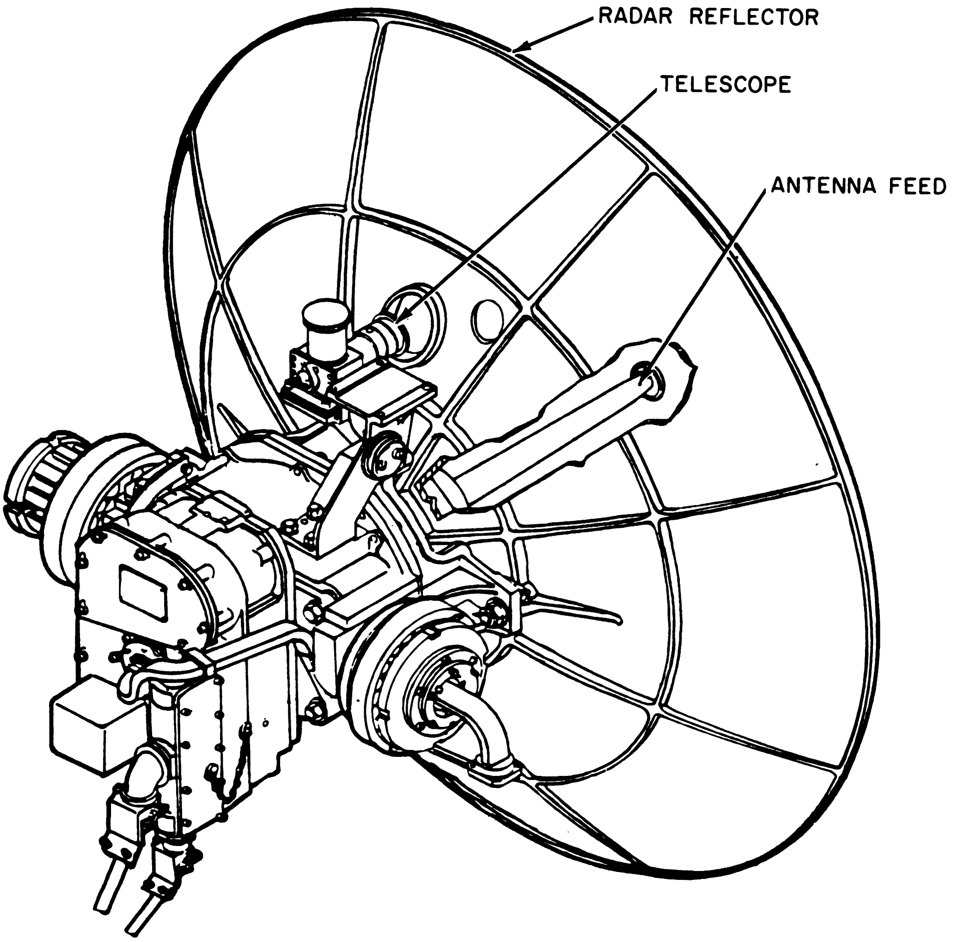

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Figure 12-14.—Typical fixed, self-contained alignment sight.

All alignment sights serve the same purpose—to represent the pointing line of the element for alignment purposes. The method of installing and aligning an alignment sight for any specific piece of equipment may be found in the applicable technical manual for that piece of equipment.

Gunner's Quadrants And Clinometers

Gunner's quadrants and clinometers are used to measure the tilt (roller path tilt) of a weapon system element with respect to the horizontal plane, or the difference in tilt between a reference element (such as a director) and some other element (such as a gun mount).

A gunner's quadrant is similar to a carpenter's level, but it is more precise. It consists of a base with an arc mounted on it; this arc is perpendicular to the base (fig. 12-15). The arc is graduated in degrees and the drum in fractions of degrees.

To measure tilt, the gunner's quadrant is mounted on a horizontal surface of the element being measured, pivot end forward (toward the pointing line of the element). The arm with the bubble tube is pivoted until the bubble is

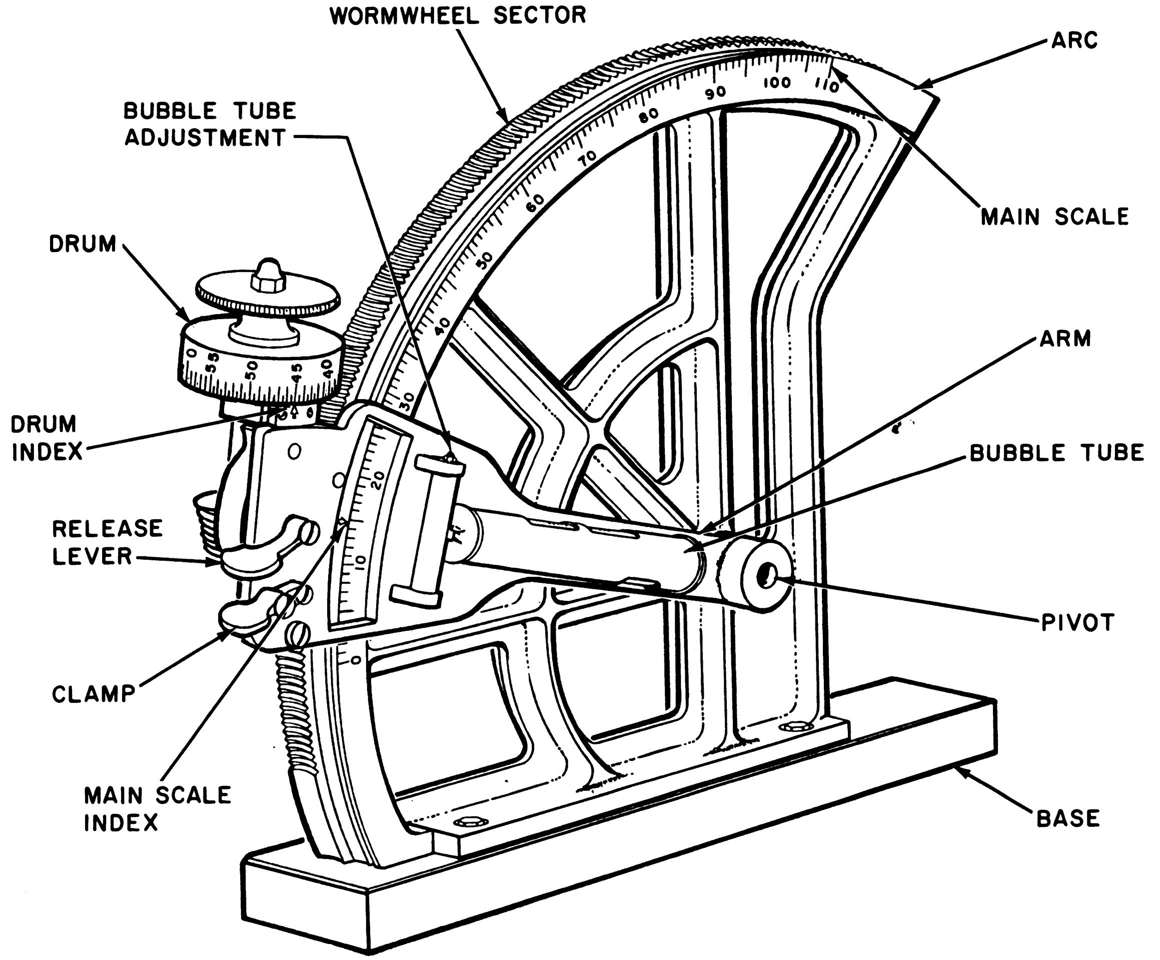

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Figure 12-15.—Gunner's quadrant.

approximately level. Next, the drum is rotated (screwed) until the bubble is precisely level. The main scale index indicates the degree of tilt of the element being checked, and the drum and drum index indicates any additional fractions of a degree.

The relationship between any roller path and the horizontal is expressed by the amount of tilt at the highest point of the path and the relative bearing of this point. Figure 12-16 shows this diagrammatically.

This data is determined by measuring roller path inclination at regular angular intervals through the full arc of train possible with the director or gun mount, then tabulating the readings and plotting them on coordinate paper. The general procedure for plotting and interpretation of the data is described later in this chapter.

Clinometers (fig. 12-17) are also instruments for measuring roller path inclination from the horizontal plane. They are limited in application because of their ability to measure only small angles. All clinomaters use a spirit level for indicating the true horizon and have some means of measuring the inclination of the base (roller path of an element being checked).

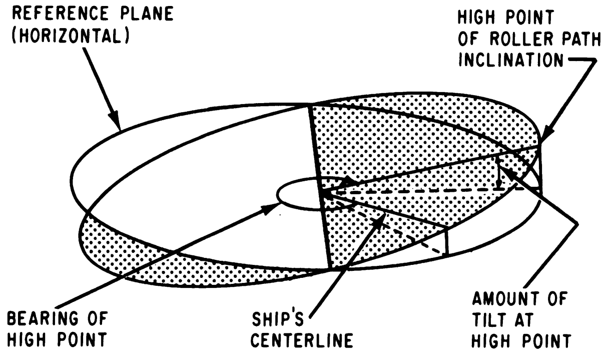

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Figure 12-16.—Relationship between roller path and horizontal.

Figure 12-17A shows a sine-bar clinometer. A sine-bar clinometer uses a screw to raise and lower one end of the bar on which the spirit level is fixed. A dial mounted on the screw and a scale attached to the spirit level are used to read the inclination of the base or roller path tilt of an element.

Figure 12-17B shows another type of clinometer commonly used for making accurate roller path inclination measurements. The Warren-Knight micrometer drum 90° clinometer is read directly to within 1′ and can be interpolated to within 15″ on the drum. An adjustable base permits reading angles from a zero position, even when working surfaces are not perfectly horizontal.

The difference in tilt between two roller paths can be determined with two gunner's quadrants or with two clinometers. This can be accomplished by attaching one device to the base of one element and the other device to the base of another element. Then, compare the readings of the devices every 10° of train of the elements. The difference in readings tells the difference in tilt between the two elements.

PRELIMINARY CHECKS

Before aligning a weapon system, ensure that each element is aligned within itself and to its bench mark or tram block, as applicable. All transmission systems must be zeroed. Synchro transmission systems must be tested to assure (1) that the transmitters are sending out a correct electrical signal for a given mechanical input, and (2) that the receivers are accurately converting this electrical signal into a mechanical or electrical signal equal to that of the transmitter.

The next step is to hold a system transmission check, using the following procedure:

1. Telephone operators must be at the stations to be tested.

2. Set the fire control switchboard for the following transmission:

   a. Directors to plot
   b. Plot to the gun mounts
   c. Director to the guns directly (bypassing the computer, where possible)
   d. Stable element to the director (to transmit level and crosslevel)

3. Turn each transmitter to various readings (usually in 10° increments) throughout its operational range and compare the received readings with the transmitted values. They should check exactly. Any errors of position, direction, or firmness of position should be investigated and remedied. Particular attention should be paid to the action of the receiver indicators when coming to rest. They should stop quickly and evenly in agreement, and there should be neither sluggishness nor oscillations.

Parallax transmission must also be checked, for it can cause errors that affect the alignment of an installation. Therefore, before alignment is started, careful checks should be conducted to ensure that the parallax units are computing proper values, and that these values are being applied in the proper direction.

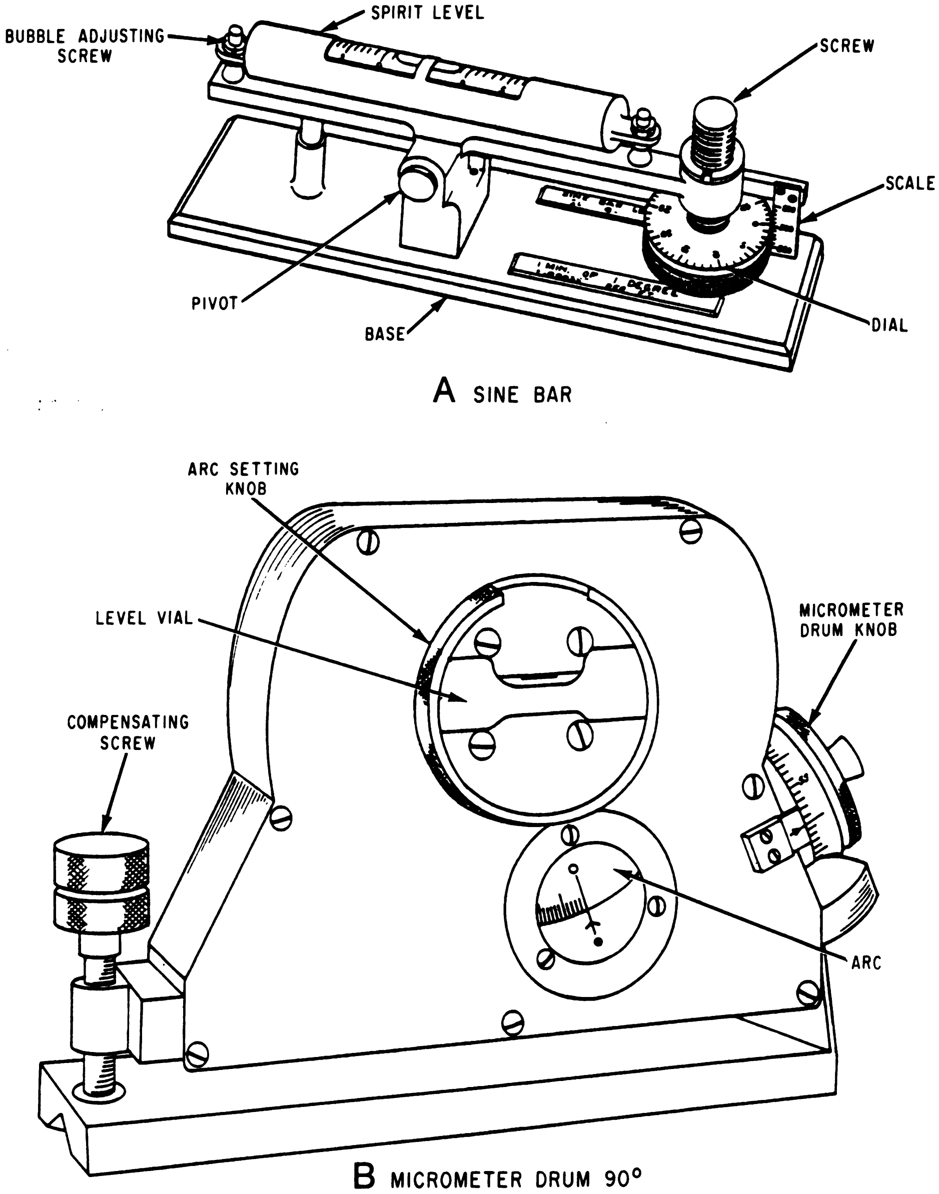

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Figure 12-17.—Examples of clinometers.

TRAIN ALIGNMENT AFLOAT

It is necessary to depend on the bench marks or tram readings established for the reference director when the ship was in drydock. Hull distortion or distortion of the reference director may cause the zero train position established by these readings to shift slightly, so that it is not exactly parallel to the lines originally established. However, this shift is small and the bench mark or tram readings can be depended upon to give satisfactory alignment until readings can be rechecked when the ship is again in drydock.

The reference director is checked on the benchmark to be sure that the zero train position of this director is parallel to the line originally established in drydock. Prior to the check, the crosslevel gear of the director (if provided) should be set to zero. The director is trained until its telescope is accurately on the bench mark or until its tram marks or blocks are aligned. The train indicator reading of the director is compared to a recorded value. If there is a difference of more than ±5 minutes of arc, the indicators are set to read the correct value. Then, the director is trained until the indicators read zero. Also, any train synchros are checked to see that they are at electrical zero.

METHODS OF AFLOAT ALIGNMENT IN TRAIN

Two methods are commonly used in the fleet to align a battery in train. One is the "Target at Known Range" method, and the other is the "Target at Infinity" method. The two procedures are exactly the same, except that in the "Target at Known Range" methods, parallax is computed and applied in the normal way to the element to be aligned. In the "Target at Infinity" method, parallax is set to zero. In this chapter, only the procedure for a target at infinity, the most commonly used method is discussed.

Target At Infinity Method

After all the preliminary checks have been made, including the bench mark check, it is possible to proceed with the actual alignment of the various battery elements. Preferably, this should be done with the ship at anchor in smooth water or when the ship is in port, tied up to a pier.

It is preferable to use the moon or a star with this method of train alignment. The sun should not be used except in case of extreme emergency, and then only when the correct light filters are used. (This is because of the risk of damage to eyesight.) The target that you select must be at an elevation of 30° or less above the horizon so that parallelism of the sights of the different elements is maintained. The greater the target elevation the greater the separation of the sights in train of the different elements due to the tilt of their roller path planes.

The train alignment procedure is conducted in the following manner:

1. Establish sound-powered telephone communications between the gun mount and the director that is to be checked.

2. Set and lock the crosslevel at zero in the director.

3. At the gun mount, put parallax in HAND and set on zero. Set the sight angle and the sight deflection on their zero values and put the gun mount in LOCAL, HAND, or MANUAL control.

If a boresight is to be used, the sight angle and sight deflection do not have to be zeroed, but should be to ease the problem of acquiring the target. The boresight keeps errors to a minumum and should be used whenever possible.

4. The director should acquire the target and relay the position information to the gun mount being aligned. At this point, it is a good idea to find out on which side of the target you will be sighting. (Some boresights have an inverted image.)

5. At the director, train to keep the selected edge of the target matched with the vertical crosshair of the reference telescope.

6. At the gun, the person on the boresight coaches the trainer to bring the vertical crosshair of the boresight within a few minutes of the selected edge of the target in such a direction that the relative motion of the target will cause the selected edge to drift across the vertical crosshair.

7. When the selected edge of the target drifts across the vertical crosshair of the boresight the operator calls "MARK" into the phone.

8. When both the director and gun are "marking" on the target at the same time, the train readings of both the director and the mount are recorded.

9. This process is repeated from both directions as many times as necessary to obtain complete data.

The errors are then computed. The algebraic difference between the two errors is the lost motion of the gun. The mean of the two errors is the gun error. The example in table 12-1 illustrates how this is done. Assume that the process is repeated three times. A recorder notes the readings on the call "mark" as the trainer trains onto the target alternately from left and right; the director dial reading was 011°00′ each time.

The total absolute difference (regardless of sign) in the three sets of readings (total of column (5) figures) is 12; dividing this by the number of observations (3) yields the mean loss motion–4 minutes. Columns (2) and (4) show the difference in each reading between the director's train indication and the gun mount's train indication at the instant of the call "MARK" (when the director train indicator reads 011°00′). These values have algebraic signs. The column (2) total is -4; the column (4) total is +8; the algebraic sum is, therefore, +4. Dividing this by 3 to get the average, we have a value of +1.33′ (rounded). This is the mean gun train indicator error; it indicates that, disregarding lost motion, the gun train indicator tends to read, on the average, 1.33 minutes higher than the director train indicator (for the same target) without ballistic or parallax corrections.

The complete train check furnishes gun errors which, when plotted with their bearings as abscissas, show a slightly ragged scattering of points, as in figure 12-18. A line parallel to the abscissa which passes through the mean of these points (i.e., with approximately equal deviations above and below the line) can be considered as the zero error line. Its distance above the abscissa is the constant error of the system, which can be removed by adjusting the train response. If a sine curve results, it indicates errors such as improper parallax settings. If the points are erratic with large deviations from the zero line, it indicates damage and should be investigated and repaired.

The gun errors should be equal and small. If they are equal and large (2 or 3 minutes larger than lost motion), it is an indication that a constant error exists, and that this error must be corrected by adjusting the train response of the mount. In so doing, the indicator showing the actual train of the element (not the dial on a synchro receiver) must be adjusted. If this adjustment is made, it is a very good idea to repeat the alignment check to ensure that the correction was in the right direction and by the right amount.

Table 12-1.—Gun Error and Lost Motion Error

(1) Approaching from the left	(2) Algebraic difference from director	(3) Approaching from the right	(4) Algebraic difference from director	(5) Absolute difference (between columns (1) and (3) regardless of sign)
1. 010°58′ -----	-2	011°02′	+2	4
2. 010°59′ -----	-1	011°03′	+3	4
3. 010°59′ -----	-1	011°03′	+3	4
Total ---	-4	-------	+8	12

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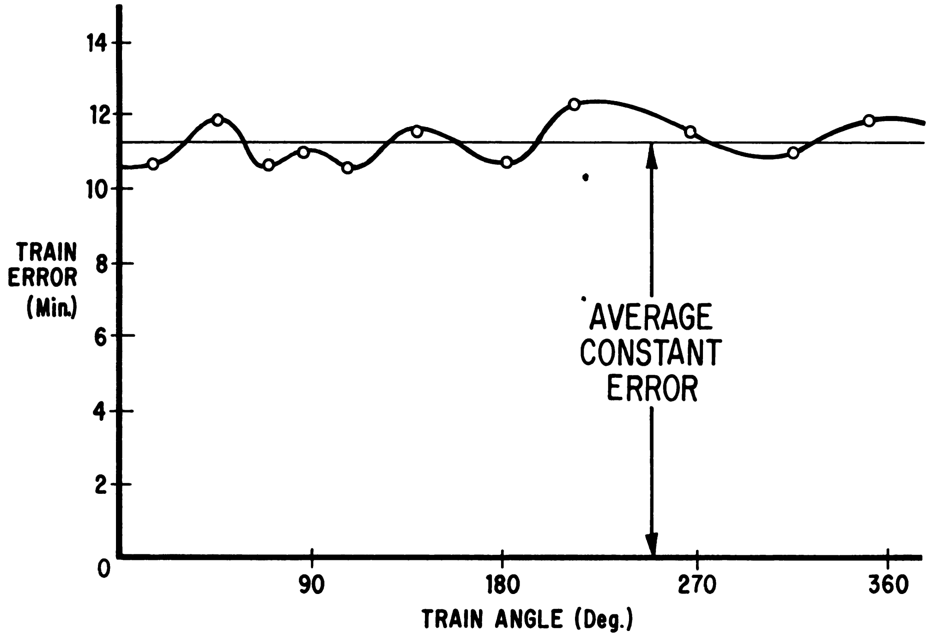

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Figure 12-18.—Typical curve of train alignment data.

ELEVATION ALIGNMENT AFLOAT

After train alignment has been completed, the battery must be aligned in elevation.

The main purpose of elevation alignment afloat is to set all the elements so that their elevation angles are measured from a plane parallel to the reference plane. When the elements are positioned in elevation so that their pointing lines are parallel to the reference plane and parallax is set to zero, the elevation indicators of the elements should read zero. Also all elevation synchros should be at electrical zero. Usually the procedures used in drydock are very hard to accomplish when a ship is afloat because of the constant rolling and pitching of the ship, even in calm water. The gunner's quadrant or the clinometer can be used to find roller path data when the ship is afloat but not getting underway and elevation alignment is necessary.

As with train, the reference element is checked on the bench mark to be sure that the zero elevation position of the element is parallel to the lines originally established in drydock. Vertical parallax and crosslevel are set to their (zero) positions. The element is then brought on the bench mark with the reference telescope. Next, the elevation indicator reading is compared with the recorded value. If there is a difference of more than ±5 minutes of arc, the indicators are set to read the correct value. Then, the element is elevated until the indicator reads zero. Also, all elevation snychros are checked to see that they are in electrical zero.

Horizon Check

To adjust the battery to its reference plane, it is necessary to compile data on the relative positions of all guns with respect to the reference plane as represented by the line of sight of the reference director. This is done by means of a horizon check, which compares the elevation angles on the indicators of the director and guns when all are laid successively on a series of points completely around the horizon. (This can also be accomplished with a gunner's quadrant or a clinometer). If the director elevation and gun elevation are compared at a common point (horizon), after accounting for any known angular differences between the two units, such as that caused by the vertical distances between the guns and the director and the angle of the gun sights with respect to the bore axis (sight angle), their elevations should be equal.

Figure 12-19 shows an example of how displacement between elements causes errors in elevation. In the example, the reference element is a director and the other element is a gun. The ship is shown in a zero roll position and both elements are shown with their pointing lines depressed to sight on the visible horizon.

The angle through which an element must be depressed below the horizontal in order to sight on the horizon is called the "dip" angle. This angle depends on the height of the element above the surface of the water. If one element is higher than the other, it must be depressed through a greater angle. Figure 12-19 also shows that different horizons are seen from elements at different heights. The horizon seen from the director is further from the ship because the greater height of the director permits seeing a greater distance over the curve of the earth's surface.

The elevation error caused by the difference in height of the elements is found by determining the dip angle for each element and then determining the differences between the dip of the reference element and each of the other elements.

Dip error is not affected appreciably by a small roll and pitch motion of the ship, because this motion does not cause the heights of the elements above the sea to change significantly. When the horizon check is performed, it is not necessary to be concerned with whether or not the deck is horizontal when the line of sight crosses the horizon.

After dip error is determined, it is subtracted from the total constant error found in the horizon check and the result is the error due to dial misalignment. This misalignment (if any) is adjusted to bring the indicators of each element into alignment with indicators of the reference element.

Following is a sample of data obtained in this way:

Bearing	Gun	Director	Difference (uncorrected gun error)
0°	1990	1976	14
15°	1991	1979	12
30°	1993	1982	*11

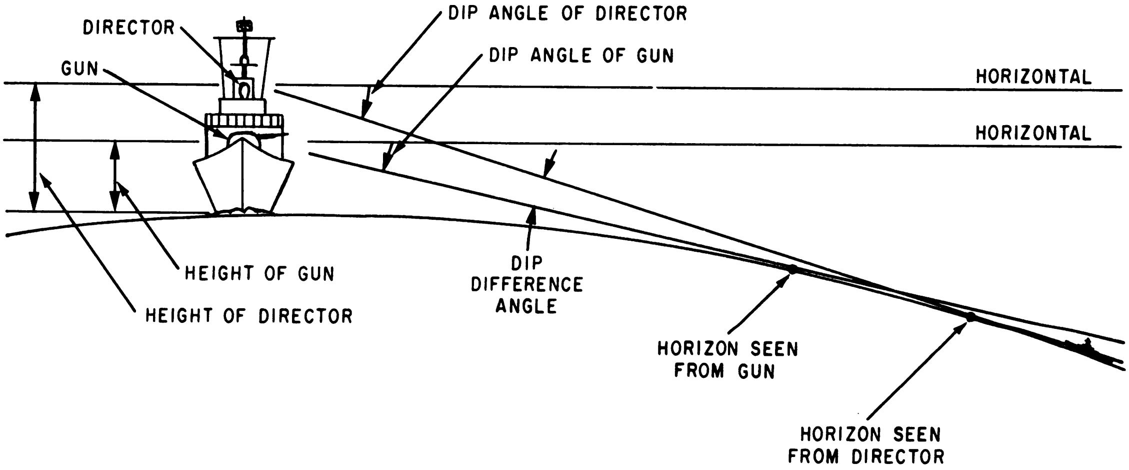

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Figure 12-19.—Dip angle and dip difference.

Bearing	Gun	Director	Difference (uncorrected gun error)
45°	1993	1981	12
60°	1991	1978	13
75°	1990	1974	16
90°	1988	1968	20
105°	1987	1963	24
120°	1988	1960	28
135°	1990	1958	32
150°	1988	1951	37
165°	1990	1950	40
180°	1992	1950	42
195°	1990	1946	44
210°	1991	1946	**45
225°	1992	1948	44
240°	1991	1948	43
255°	1995	1955	40
270°	1994	1957	37
285°	1995	1963	32
300°	1993	1965	28
315°	1990	1966	24
330°	1987	1968	19
345°	1988	1972	16
360°	1990	1976	14

*High point.
**Low point.

There are three methods by which the varying factors can be separated from the constant factors to determine the roller path misalignment between the gun and the director. The methods are the rectangular coordinate method, the 60° polar coordinate method, and the 180° polar coordinate method.

Rectangular Coordinate Method

The preceding tabulated data is plotted by the rectangular coordinate method as shown in figure 12-20.

Note that the difference between gun elevation and director elevation varies with different angles of train. If the gun roller path compensator had been properly set (no uncorrected inclination), these differences would have been constant and the data would plot as a straight line. As it is, however, the differences vary, indicating uncorrected inclination, and the data, therefore, plots as a sine curve. The example shown here is for the full 360° arc of train, which is a condition almost never realized in practice. Hence, while both a high point and a low point are shown on the sample curve, only one of these points may be present on the curves obtained for an actual installation.

After plotting and drawing the curve, find the zero axis in the center of the curve. Either of two methods may be used.

1. If both the high point and low point have been plotted, add the high point and low point values, and divide by 2. The resulting value is the center of the sine curve through which the zero axis passes. Plot this either on the y-axis or on the curve, and draw a line through it parallel to the abscissa. You have now drawn the curve's zero axis.
2. The alternate method is to take a point on the sine curve 90° from the high point or the low point, and draw through it a line parallel to the abscissa.

The distance of the zero axis above the abscissa represents the error due to all causes other than roller path inclination. Figure 12-20 shows how this error is broken up into component parts. Dip difference is a known value and the remaining error represents the system error. This constant system error can be removed by adjusting the elevation response at

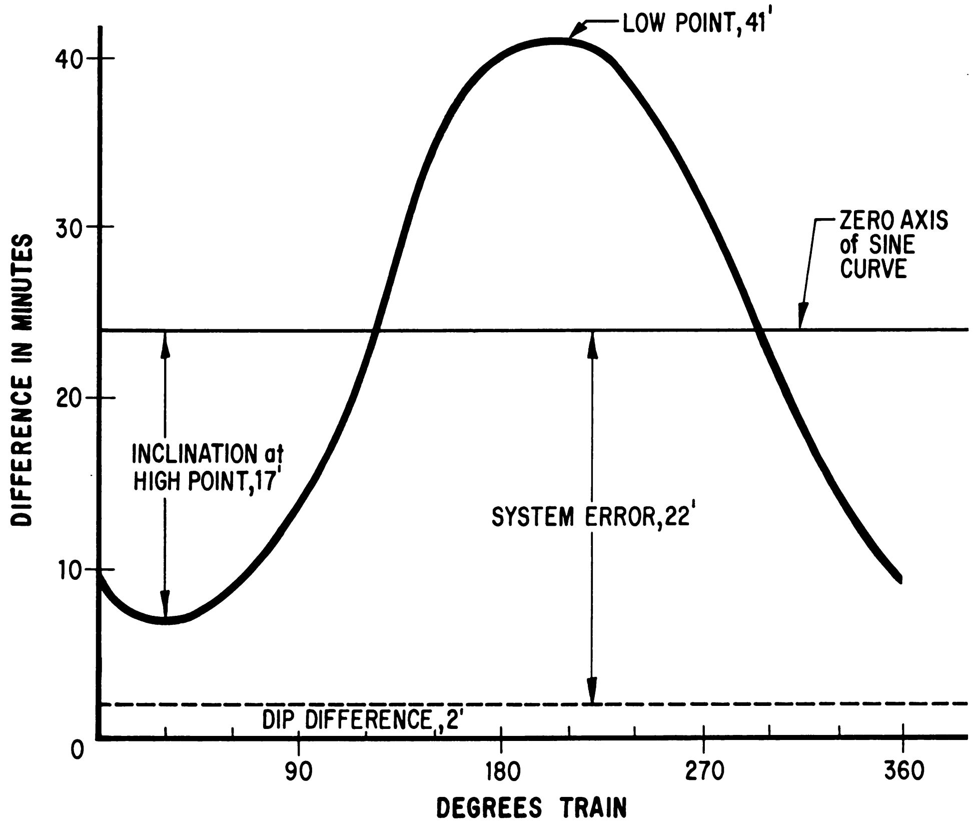

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Figure 12-20.—Sine curve plot of horizon check data.

the gun. When this is done, tram values in elevation will have to be corrected.

The low point of the curve represents the bearing and inclination of the high point of the gun roller path, with respect to the reference plane (in this case, the director roller path). If no low point is shown on the plotted curve, it may easily be calculated, since it occurs at a bearing 180° from the high point of the curve. Further, it occurs at the same distance from the zero axis of the curve as did the high point. The bearing of the low point of the curve represents the bearing of the high point of the gun roller path. The distance of the low point below the zero axis of the curve represents the inclination of the gun roller path. In the example shown in figure 12-20, the high point of the gun roller path (represented by the low point of the sine curve) is at 30° train, and the inclination at that point is 17 minutes. Thus, for this example, the following desired data is available:

Bearing of high point	30°
Inclination of high point	17′
Constant error of system	22′

Note that the low point of the sine curve is the high point of the gun's roller path. We know that the uncompensated roller path inclination plots as a sine curve. When the gun is trained to the highest point on its roller path, the actual gun elevation to the horizon is at its lowest value with respect to the reference plane. This occurs because the gun's roller path has not been completely corrected to the reference plane. In other words, the high point of the gun's roller path has raised the gun above the reference plane, and to elevate it to a given target now requires less elevation angle between the gun bore axis and the gun roller path. With gun elevation at its lowest value, the difference between gun and director elevation is at a minimum; a minimum difference is the low point of the sine curve.

60° Polar Coordinate Method

Because the forming of a curve in the rectangular coordinate method is difficult, it is preferable in many cases to plot the data on polar coordinate paper. When this is done by the 60° method, the curve resulting from roller path inclination takes the form of a circle. This method also eliminates the need to make corrections for sight angle and dip difference. However, the constant system error is not indicated or measured, therefore, a sine curve must still be constructed to determine if any system error is present.

The actual procedure for analyzing the sample data is to obtain or construct a form similar to the one in figure 12-21 and list the data as shown.

The bearings and differences for 30° increments only have been used to simplify the computations, but all of the information could just as easily have been utilized for 15° or 10° increments.

In column (1), list the train angle in degrees. List in column (2) the difference between the gun and director readings.

In column (3), add 60° to each of the train angle readings in column (1), and again in column (4) list the difference for that particular train angle. Columns (3) and (4) show the same data as columns (1) and (2) except that it is offset by 60°.

Subtract the readings in column (4) from the readings in column (2) and list the differences in column (5). If a reading in column (4) is greater than the related reading in column (2), the result will be negative. Indicate this by a minus sign.

The values that have been listed on the form must now be transferred to the polar coordinate graph. Using the train angles listed in column (1), plot the difference in column (5) on the graph paper. Be sure to plot any negative values 180° from the direction of the related bearing angles.

The plotted points should progress approximately in a circle for the first 180° and then progress over the same circle in the next 180°. The points plotted in the second 180° should be superimposed on or very close to the points in the first 180° (fig. 12-21).

Now, fair a circle through the plotted points, ensuring that the circumference passes through the pole of the graph.

The maximum inclination is indicated by the diameter of the circle in the direction of the point farthest from the pole of the graph. Draw this diameter. Determine the magnitude of the inclination by noting the length of this diameter (vector).

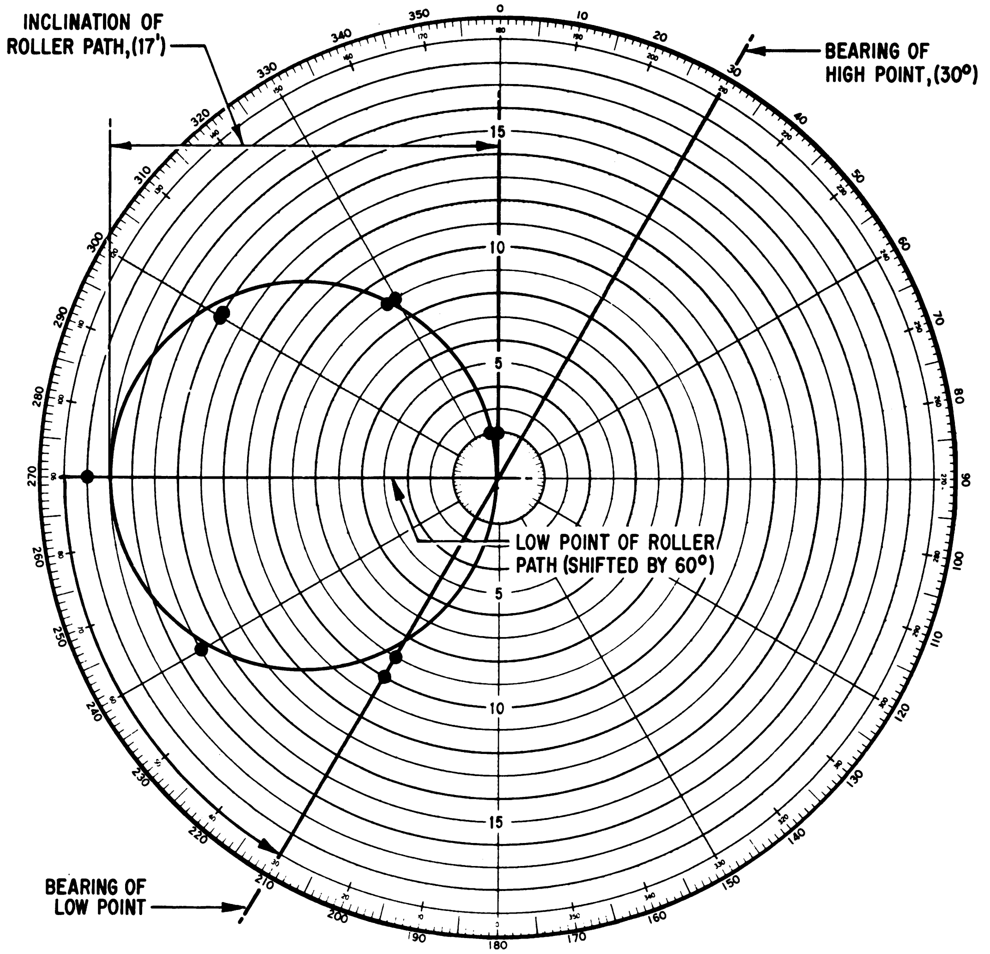
The end of this vector actually represents the low point of the roller path, shifted by 60°. The actual bearing of the roller path low point is found by subtracting 60° from the vector bearing. In the example this is 270° - 60° = 210°, the bearing of the low point.

To determine the bearing of the high point, shift the low point 180°. The high point is now 30°. This is the same as the bearing of the high point found by the rectangular coordinate method.

180° Polar Coordinate Method

The 180° polar coordinate method is very similar to the 60° method described in the preceding sector, and has the same advantages and disadvantages. For instance, it does not show system error.

The data listed in columns (1) and (2) is the same as that used in the 60° method. However the data in column (3) is shifted by 180° instead of 60°, and the difference in column (4) is recorded for these train angle values. The differences in column (5) are determined in the same manner as in the 60° method and the



(1) TRAIN ANGLE DEGREE	(2) DIFFERENCE UNCORRECTED GUN ERROR	(3) TRAIN ANGLE DEGREE	(4) DIFFERENCE UNCORRECTED GUN ERROR	(5) DIFFERENCES COLUMN 2 – COLUMN 4
0(360)	14	60	13	1
30	11	90	20	-9
60	13	120	28	–15
90	20	150	37	–17
120	28	180	42	–14
150	37	210	45	-8
180	42	240	43	-1
210	45	270	37	8
240	43	300	28	15
270	37	330(0)	19	18
300	28	360	14	14
330	19	30	11	8
360(0)	14	60	13	1

170.193

Figure 12-21.—Analyzing roller path data by the 60° polar coordinate method.

points are plotted by the same method (fig. 12-22). (Note the change in scale when compared to figure 12-21.)

The difference between the 60° and 180° methods becomes apparent after you have faired in the circle. After you fair in the circle, mark the center point of this circle. The maximum inclination of the roller path lies on the diameter (vector) drawn from the graph pole toward the farthest point plotted, but is only one-half the vector value. The bearing of the high point is found by shifting the low point 180°. Again you have a high point bearing of 30° and an inclination of 17′.

Of the three methods of analyzing roller path data, the most commonly used one is the rectangular coordinate method. This is because all computations can be performed at one time, whereas in the 60° and 180° methods a separate sine curve must be plotted to determine the amount of system error.

CALCULATING CORRECT COMPENSATOR SETTING

The horizon check is usually made with some setting already on the roller path tilt compensator of the gun. The tilt found by the check, therefore, is not the total inclination but only the uncorrected inclination. It is an additional inclination to that for which the compensator has been set. This newly discovered inclination must be added vectorially to the inclination previously known to exist, in order to determine the total inclination for which the compensator must be set. This may be done graphically, as shown in figure 12-23. In this figure, the results obtained previously are used to illustrate the following method:

1. The line OA is drawn to represent zero train.

2. The original setting of the compensator (8.5′ at 150°) is plotted as line AC. This is done by measuring off the angle clockwise from OA, and measuring the inclination on that line to a convenient scale.

3. The inclination found (17′) is plotted as AB on a bearing of 30°.

4. CD is drawn parallel to AB, and BD is drawn parallel to AC. These lines intersect at D.

5. Line AD is drawn from the origin to D. This line represents the total inclination. Its bearing (59°) and length (15′) may be read according to the previously established scale. This is the data that must be set into the compensator.

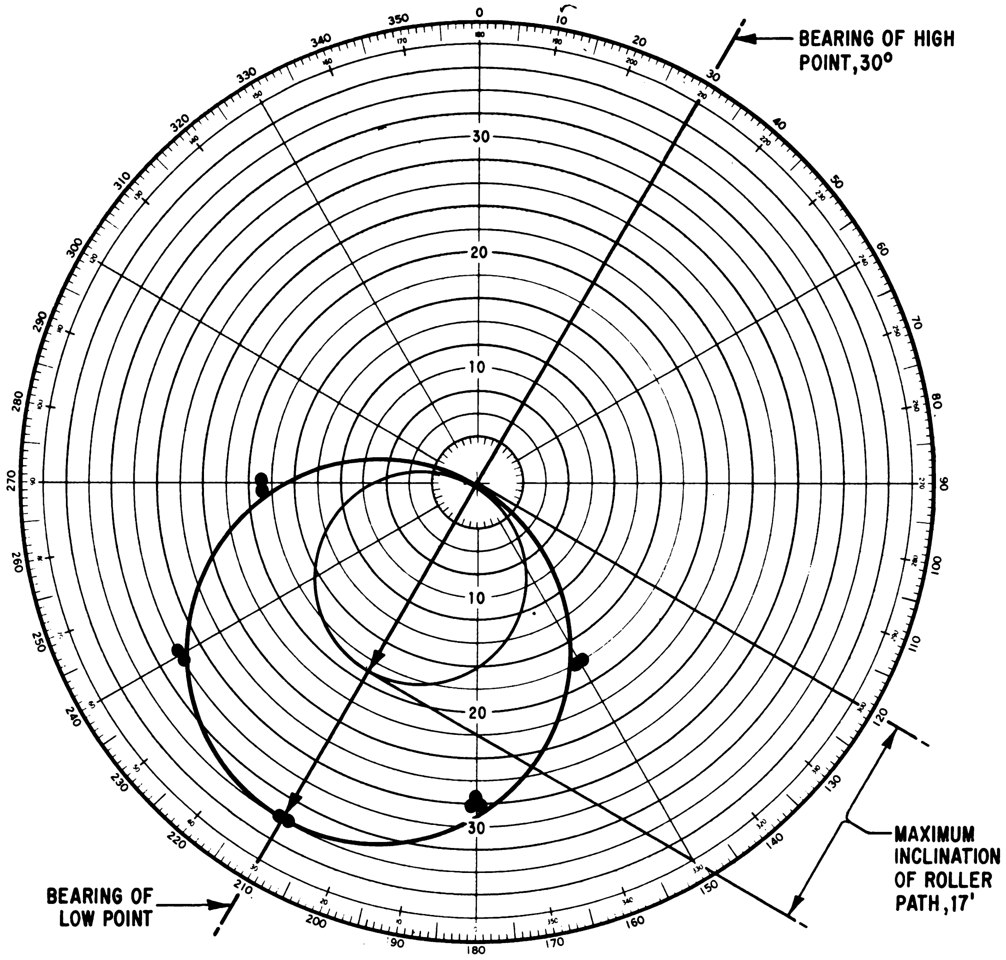
It should be noted that compensators are constructed to read the error rather than the correction. Thus, if the error is 15′ at 59°, the bearing scale is turned to 59°. Then the inclination of 15′ is set on the inclination scale, and the adjustment is completed.

RADAR ANTENNA ALIGNMENT

To align the radar antenna, adjustments must be made in train, elevation, and crosslevel. The elevation axis of the radar antenna must be parallel to the elevation axes of the director's optical equipment. This is done so that the radar antenna and the director optical equipment will elevate in planes that are parallel throughout the range of movement. The lines of sight of the director optical equipment and the radar antenna are perpendicular to their elevation axes, and all are moved throughout the same elevation angle so that they remain parallel. If such a condition did not exist, it would be impossible to direct both the radar antenna and the lines of sight onto a target.

Normally the radar antenna mount is aligned with the optics of the director upon initial installation. This involves locating and shimming the antenna mount until it is parallel with the optics. This alignment is usually accomplished by the installing yard, and requires the use of special boresighting equipment and tools.

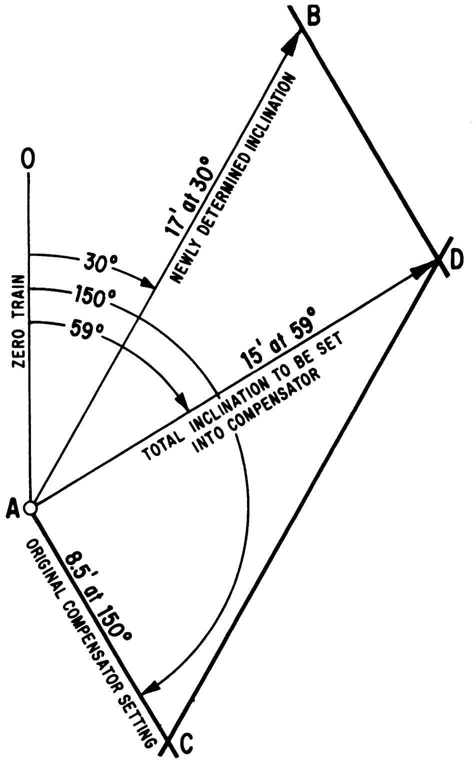
Train and elevation antenna alignment afloat is done by locking the radar on a target at least 4000 yards away and checking to see that the vertical crosshair in the trainer's telescope and the horizontal crosshair of the pointer's telescope are on target. If the vertical crosshair of the trainer's telescope is not on target, the radar antenna reflector is adjusted using the



(1) TRAIN ANGLE DEGREE	(2) DIFFERENCE UNCORRECTED GUN ERROR	(3) TRAIN ANGLE DEGREE	(4) DIFFERENCE UNCORRECTED GUN ERROR	(5) DIFFERENCES COLUMN 2 – COLUMN 4
0 (360)	14	180	42	–28
30	11	210	45	–34
60	13	240	43	–30
90	20	270	37	–17
120	28	300	28	0
150	37	330 (0)	19	18
180	42	360	14	28
210	45	30	11	34
240	43	60	13	30
270	37	90	20	17
300	28	120	28	0
330	19	150	37	–18
360 (0)	14	180	42	–28

170.194

Figure 12-22.–Analyzing roller path data by 180° polar coordinate method.


B
O
D
A
C
ZERO TRAIN
30°
150°
59°
17' at 30°
NEWLY DETERMINED INCLINATION
15' at 59°
TOTAL INCLINATION TO BE SET INTO COMPENSATOR
8.5' at 150°
ORIGINAL COMPENSATOR SETTING

110.86

Figure 12-23.—Compensator-setting calculation.

adjusting bolts until the crosshair is on target. If the horizontal crosshair of the reference telescope is not on target, the elevation adjustable coupling of the radar antenna is turned until the crosshair is on target.

FINAL OPERATIONAL CHECK

Modern weapon systems are operated almost exclusively in automatic control, except under certain special conditions or in emergencies. Therefore, it is particularly important for a system to be aligned accurately for automatic operation. If the alignment methods described in this chapter are employed, so that the indicators of each element are aligned accurately with the pointing line, a good alignment should be obtained. However, it is advisable to check the results under conditions which approximate those under which the equipment will be operated.

Perform the check with the installation in automatic control, and with the parallax equipment functioning. If the weapons are equipped with sight telescopes, use them rather than boresights. If a weapon is equipped only with open sights, a boresight telescope will be necessary.

If possible, select various targets at different bearings and at ranges which will be approximately equal to the mean battle range of the equipment. The target should produce a slow bearing rate, so that accurate tracking is not difficult.

If the director cannot stay on the target continuously, the operator should inform the operators at the guns by telephone when it is on, by calling "MARK." The operator at each gun observes the target through the sight telescope or the boresight, and makes a note of any train error present when the director is on the target. This is done for targets at various bearings, some moving to the right and some moving to the left. In this check, some small error is to be expected because there is always some lag and lost motion in the followup servomechanisms. However, the error observed when tracking to the left should be essentially equal to that observed when tracking to the right, and should be in the opposite direction. If the errors do not change direction when the direction of tracking is changed, or if they are considerably larger for one tracking direction than the other, a misalignment is indicated. This can be corrected by adjusting the train transmission system; but before any adjustment is changed, a careful analysis should be made to be certain that the error is not caused by some other factor. For example, a misalignment of the sight telescope could cause an error. This should be corrected by boresighting the telescope—not by adjusting the transmission system. In this case, adjusting the transmission system would bring the sight telescope on, but would result in firing errors. If, after careful analysis, an adjustment is made to the transmission system, a check should be made to see whether or not a corresponding adjustment must be made to the indicators or any other part of the equipment.

SUMMARY

This chapter has presented the procedures involved in weapon systems alignment. It is not intended to be a substitute for established alignment procedures. It can, however, be referred to for an explanation of some of the basics of shipboard alignment. Before starting any segment of the alignment procedure, consult your system OPs for the correct detailed procedure.

CHAPTER 13

SPOTTING AND NAVAL GUNFIRE SUPPORT

Spotting is defined as the estimating of the corrections in range, elevation, and deflection necessary to hit a target. A spotter observes the fall of shot and estimates the corrections required to bring the gun on target. Spotting is an integral part of fire control; therefore, it is necessary for all fire control technicians to understand the procedures governing it.

Spotting procedures apply principally to surface and shore targets. Spotting on air targets is usually unsatisfactory because of the speed of the aircraft and the short time of the engagement. All spotting must be done quickly and accurately if a target is to be hit.

Naval Gunfire Support (NGFS) is a special evolution where a ship's guns are used against shore targets. Frequently, the targets cannot be seen by the radar or optical equipment of the fire control system. Therefore, the fire control system has to be operated manually, instead of automatically as with air or surface targets. This calls for skilled and competent GFCS operators.

SPOTTING AND GUNFIRE TERMINOLOGY

Before proceeding, let us consider some terms that relate to gunfire and spotting. The terms are as follows:

SLOW FIRE.—In slow fire, firing is deliberately delayed to allow the application of spots or the conservation of ammunition.

SALVO.—A salvo consists of one or more shots fired simultaneously by the same battery at the same target.

SLOW SALVO FIRE.—In slow salvo fire, the guns are loaded on command and fired together at a fairly slow rate.

RAPID SALVO FIRE.—In rapid salvo fire, the guns are loaded on command and fired together at a rapid rate.

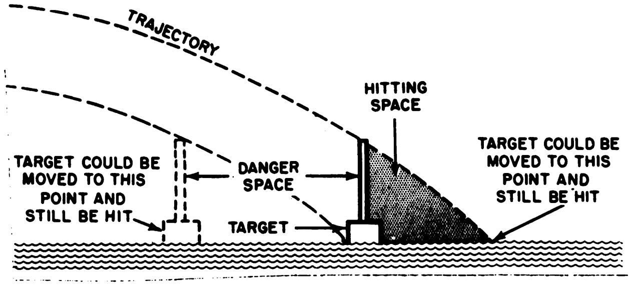
RAPID CONTINUOUS FIRE.—Rapid continuous fire is the fastest firing method for 5-inch guns. The gun's firing key is locked in the closed position, and the rate of fire depends only on the loading speed.

DISPERSION.—Dispersion is the separation between the fall of shots when a salvo is fired. Theoretically, all rounds fired in a salvo should land in the same spot, but this is not usually the case. Normally, there is some separation.

Dispersion is caused by errors which are inherent in the firing of guns under normal operating conditions. These errors are due to such variations as minor differences in the weight and temperature of the powder, irregularity in the operation of the gun recoil system, the misalignment of the guns, etc. Because of these errors, some dispersion can always be expected in the points of fall of the projectiles from guns fired in a salvo under normal operating conditions. This must be taken into account when a spotter makes corrections to bring the fall of shots onto the target.

HITTING SPACE.—Hitting space for a target (usually measured only in range) is the distance behind the target (measured along the line of fire) that a shot through the top of the target will strike the horizontal plane through the base of the target (fig. 13-1). It includes the projection of the target's vertical height upon the plane of the water, plus the target's horizontal dimension in the line of fire (or depth). Hitting space in deflection is the angle subtended by the target.

DANGER SPACE.—The danger space for a target is the distance in front of the target,


TRAJECTORY
HITTING SPACE
TARGET COULD BE MOVED TO THIS POINT AND STILL BE HIT
DANGER SPACE
TARGET
TARGET COULD BE MOVED TO THIS POINT AND STILL BE HIT

92.57
Figure 13-1.—Hitting space and danger space in range.

measured parallel to the line of fire, that the target could be moved toward the firing point, so that a shot striking the base of the target in its original position would also strike the top of the target in its new position (fig. 13-1). At most, danger space is virtually equal to hitting space for a given trajectory.

STRADDLE.—A straddle is obtained from a salvo in range (or deflection) when, excluding wild shots, some of the shots of that salvo fall or detonate short of the target, and others beyond it (or right and left, respectively, for deflection).

SPOTTING

Now that you are familiar with some of the terms relating to spotting and gunfire support, we will discuss some of the problems encountered in spotting.

UNPREDICTABLE ERRORS

Since dispersion of individual shots is caused by unpredictable errors, it is logical to assume that no two salvos will be exactly alike. Hence, the fall of the shots of a given salvo can be expected to differ in location from the fall of shots of other salvos.

The average shift between successive falls of shot is usually so small that it is difficult for the spotter to estimate the difference. Therefore, the spotter should not be too quick to spot when only one or two salvos seem to wander off the target during a string that is, in general, satisfactory.

CONTROL ERRORS

The only accidental errors considered so far have been those which affect the individual guns of a battery. These are known as gun errors and should be distinguished from another class of accidental errors which affects the battery as a whole. These are known as control errors and include computational errors, transmission errors, and in director controlled fire, director pointing errors. They are not reflected in increased pattern sizes (increased dispersion among the guns), but are characterized by increased dispersion or error in the fall of shots themselves.

There are three general control inaccuracies which may cause fall of shot errors. These are listed in the order of probable frequency of occurrence and magnitude of effect.

1. The computer is set up with incorrect values.
2. The ballistic corrections are based on incorrect values (I.V., wind, air density, etc.)
3. The battery is not properly aligned with the director.

Incorrect Computer Setup

Determination of target course and speed is accomplished by radar and plotted by personnel in CIC, or by rate controlling. The correct values of these two variables are difficult to determine. Therefore, they are the chief cause of incorrect computer setup, and hence, the chief source of error in the fall of shot.

Present range to target is valid only so far as its measurement is accurate. An error in basic range measurement directly causes an error in the fall of shot.

Measurement of ownship course and speed usually is reasonably accurate, but any inaccuracies result in an error in the fall of shot.

Inaccurate Ballistic Corrections

The computer determines corrections for variations from standard conditions. Determination of these corrections based on incorrect ballistic quantities (wind, I.V., air density, etc.) will give a total ballistic correction that will result in a corresponding error in the fall of shot.

Poor Battery Alignment

An error in the fall of shot can be caused by misalignment between the controlling director and the gun battery. Such misalignment is generally caused by failure to align all of the gun battery and directors. A battery aligned with one director is not necessarily aligned with another. Frequent alignment checks can assist in elimination of this cause of error.

SPOTTER QUALIFICATIONS

The spotter has several functions and duties. In order to perform them effectively, the spotter should have the following qualifications:

1. An even, calm temperament (Not excitable under stress)
2. Sound judgment
3. Decisiveness
4. Alertness
5. Normal eyesight, hearing, and speech.

The primary function of the spotter is the correction of range and deflection errors in the fall of shot, so as to bring the guns on the target. Prompt and accurate correction of initial errors may be the deciding factor in a naval engagement. The spotter bases any corrections on personal observations combined with those of the fire control radar operator. As a rule, in good visibility, the spotter estimates the necessary deflection corrections. Range corrections are obtained from a radar operator. Under unfavorable conditions, both range and deflection corrections are obtained from the radar operator.

Besides the primary function of correcting the fall of shot, the spotter must keep CIC informed of the tactical situation.

METHODS OF SPOTTING

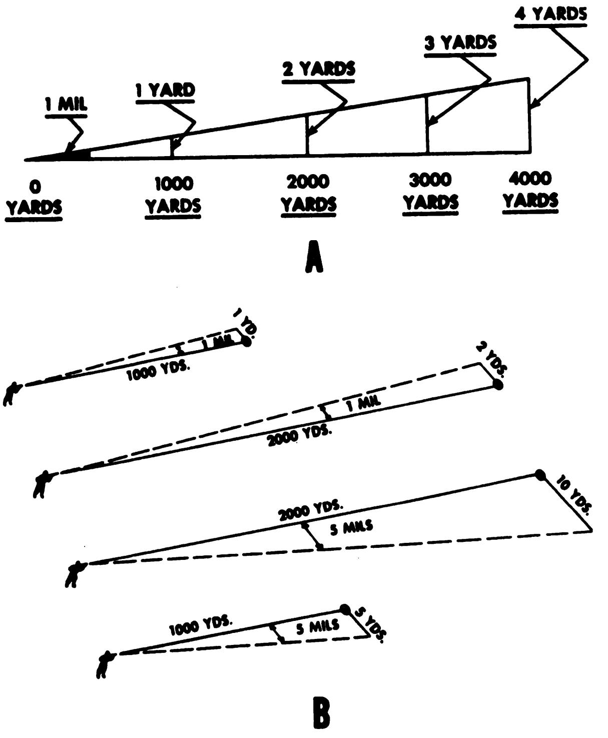
There are two methods of spotting–visual spotting and radar spotting. For surface targets, spotting consists of range spots and deflection spots. For shore targets, spotting consists of range spots, deflection spots, and height spots. Before discussing visual and radar spotting, let us discuss some peculiarities about spotting in deflection and range.

Spotting in Deflection

Because it is simpler to make range spots when there is no deflection error (particularly at long ranges), the spotter customarily calls deflection spots first. The unit used in deflection spotting is the angular mil.

THE MIL AND ITS USE.–You are already acquainted with the angular mil because it was discussed in chapter 5. There are about 6400 mils to a circle, and 1 mil is about .056 degrees, or 3.37 minutes of arc. The reason for using the mil as an angular unit in measuring deflection, rather than using degrees or minutes, is that it has a very useful property. If a distant object appears to an observer to have an angular width of 1 mil, then the actual width of the object is 1/100th of the range.

Telescopes, binoculars, and other optical devices for naval use often have reticles with mil scales etched on them. If you were to use such binoculars to look at, say, a 30-foot boat broadside at a range of 1000 yards, the image you would see in the binoculars would have an angular width of 10 mils. Figure 13-2 shows additional graphical examples of the relationship between mils and range. Part A of the figure shows how 1 mil subtends different linear distances at different ranges, and part B shows several other examples of the relationship. To



55.145
Figure 13-2.—The angular mil and how it is used.

bring the use of mils down to a more practical level, look at figure 13-3. What is the linear size in deflection of salvo A's pattern?

Salvo A at a range of about 11,500 yards subtends 5 mils. One-thousandth of the range is 11.5 yards; multiplying by 5 (mils) gives an actual pattern width in deflection of 57.5 yards. As a practical matter, of course, it is absurd to specify a pattern width down half a yard; rounding off, the answer would be about 58 yards.

In estimating deflection spots, use target width in mils as a guide.

ALLOWING FOR SPLASHES.—With a high-speed surface target, the spotter should bear in mind that the fall of shot in deflection should be held behind the point of aim to allow for target travel while the splashes are forming. Do not assume that full splashes form instantaneously at the impact of a salvo. The time lag is only a few seconds at most but is sufficient to allow considerable movement of a fast target.

Spotting In Range

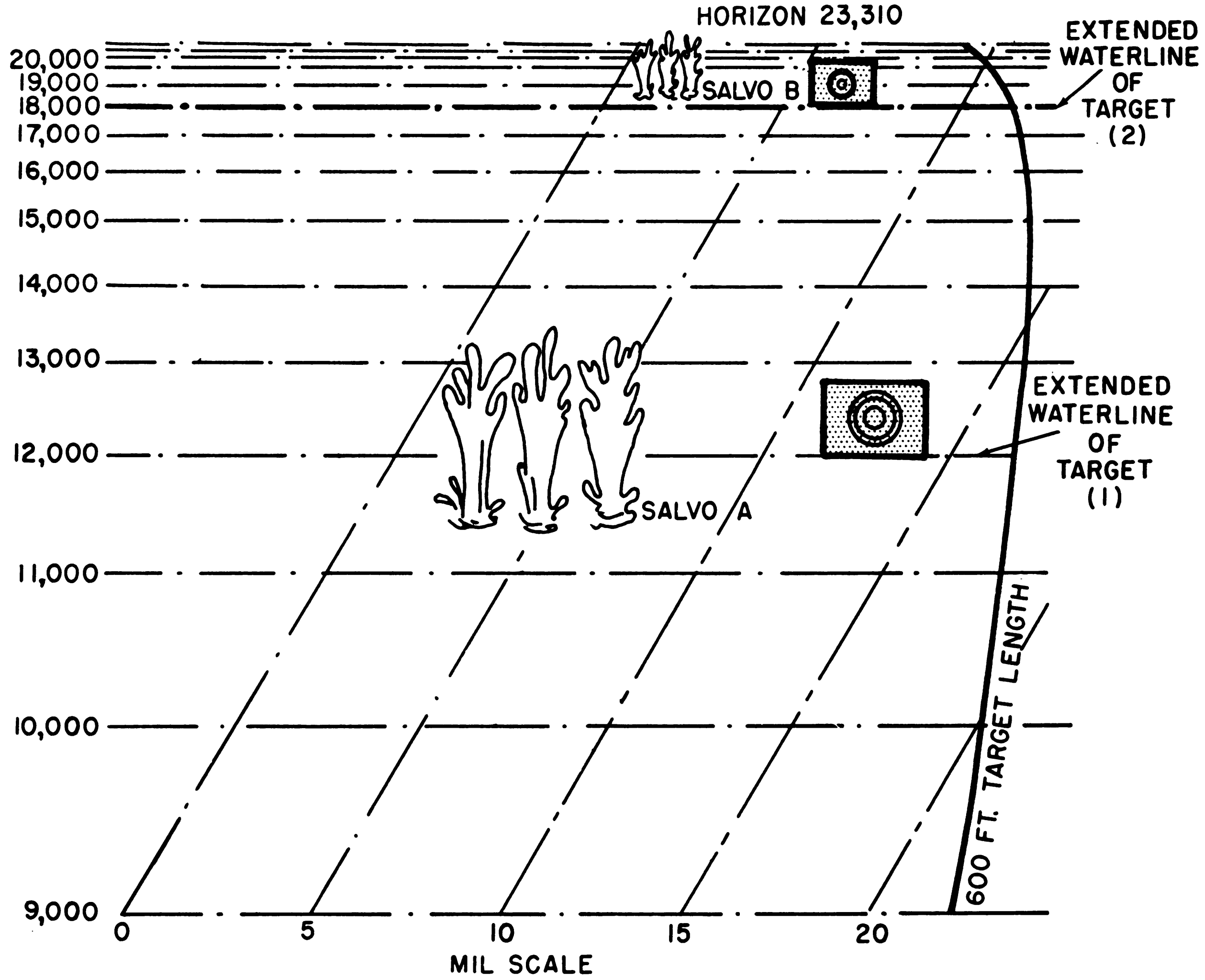
Spotting in range is more difficult than spotting in deflection. There is no convenient angular measure that is uniformly applicable at all ranges, like the almost foolproof mil.

Figure 13-3 is adapted from a typical spotting diagram. It shows schematically how different ranges look to an observer 100 feet above the water surface. The lateral broken lines represent ranges in increments of 1000 yards; the diagonal broken lines represent angular mils; and the curved solid line at the right shows the apparent length in mils of a 600-foot broadside target at various ranges. Unfortunately, the natural seascape is not marked with these handy reference lines, but the diagram is a helpful guide in learning how to estimate ranges. It is used in conjunction with such training aids as miniature spotting boards, and with observation during target practice.

The range lines in figure 13-3 represent the angular distance below the horizon at which any object would appear from a height of 100 feet, if observed on the corresponding range lines. The distances between the range lines represent the apparent range differences as viewed by an observer at the height (in this case 100 feet) for which the diagram was constructed.

A study of figure 13-3 shows that salvo A is clearly short, by about 500 yards, of the imaginary extension of the waterline of a target at 12,000 yards. However, the error of salvo B, fired at a target at 19,000 yards, is not so apparent. The 500-yard error of salvo B is difficult to see when compared with the extended waterline of the target. Thus, for shipboard spotting at such a range, the splashes must be in line with some portion of the target before the spotter can reasonably tell whether the salvo is long or short, to say nothing of estimating the amount of error.

In addition to its use for estimating range and range errors, the spotting diagram shows the number of mils a given target length will subtend at any given range. For example, in figure 13-3,



92.58

Figure 13-3.—Practice diagram for range spotting.

a 600-foot target will subtend 20 mils at a 10,000-yard range.

One of the most common mistakes made by the untrained spotter is to underestimate the amount of range error at long ranges, because a given range error will subtend a much smaller angle at long ranges than it does at short ranges. However, with good visibility and from a height of 120 feet or more, the error in the fall of shot can usually be estimated with reasonable accuracy at ranges up to 15,000 yards by observing the position of the bases or slicks of the splashes relative to the target waterline.

Visual Spotting

There are three methods of visual spotting:

1. The direct method
2. The bracket-and-halving method
3. The ladder method

The method used depends on the type of battery firing, the type of target, the visibility, and the range.

DIRECT METHOD.—Spotting by the direct method is, as its name implies, the spotting of salvos (splashes) directly to the target. This is the most desirable procedure, but its use is limited to short ranges and good visibility conditions. For reasonably accurate visual spotting at a range of 15,000 yards, a spotting height of 120 feet is required. The splash must be relatively close to the target, and the computer setup fairly accurate.

A thoughtful analysis of the problem, with reference to the spotting diagram in figure 13-3, reveals that the greatest limitation of the direct method in visual spotting is in range. Deflection spots can be made with equal accuracy at any visible distance. If, then, air observation is available, and the plane spots in range with the ship spotting in deflection, the direct method can be used by the battery at any range at which a portion of the splash is visible to the shipboard spotter. Air spotters cannot spot accurately in deflection unless they have a line of sight containing the firing ship and the target.

Spotting the fall of shot at very short ranges differs from other spotting problems in that range errors are not difficult to judge. However, in determining deflection errors at short ranges, consideration must be given to the travel of the target and the spotter's position relative to the line of projectile flight. For example, with the firing ship and target on opposite courses, target to starboard, a shot fired with correct deflection but long in range will appear to the spotter to be in error to the left of the target. Special short-range splash diagrams aid the spotter in this type of firing.

BRACKET-AND-HALVING METHOD.—Bracket-and-halving is used at long ranges when no air or radar spot is available, and the range is estimated. At great distances, it is impossible to tell if a splash is short of or over a target, unless the two are in line. If the splash and target are not in line, the first spot is made in deflection only. When the target and splashes are in line in deflection, a range spot is made in such a direction and amount as to "cross" the target definitely. The direction of the next spot is reversed, and the size of the spot is cut in half. This "halving" is continued until a straddle is obtained, at which time it may be appropriate to shift to rapid partial salvo or to rapid continuous fire.

LADDER METHOD.—When ranging is difficult and visibility poor because of fog, smoke, or darkness, the ladder technique is valuable. There are many variations of this technique, but the basic procedure is along the following guidelines:

1. Fire is deliberately opened short.
2. Succeeding salvos are fired to approach the target.
3. As soon as the target is crossed, the steps are reversed and halved until the target has again been crossed.

After the target is straddled, a rocking ladder may be used with slow timed fire, or with rapid partial salvo or continuous fire. In a rocking ladder the pattern is shifted back and forth across the target by small arbitrary successive spots, such as +100, 0, -100, ... , introduced at the computer. Its effect is to increase the pattern size, which may be valuable when firing against a target capable of rapid maneuvering. The rocking ladder can be used in conjunction with air or radar spotting, so long as the spotter is kept informed that this technique is being used. Ladders are not particularly adaptable to fast-moving targets.

Radar Spotting

Radar spotting has proved to be both accurate and reliable within the range of surface batteries. Radar provides a means of spotting which is independent of conditions of visibility, so that blind spotting is possible with blind firing.

Shell splashes appear on the scope as fluctuating echos which last for several seconds, depending on the size of the projectile and the range. The large column of water thrown up by the projectile produces the echo. Salvos produce larger or multiple echos on the scope.

If the projectile stays within the vertical limits of the radar beam, its flight to the point of impact can be followed on the main sweep scope. The projectile produces a small, weak, moving echo which begins at the edge of the scope and moves out in range toward the target. At the point of impact the echo stops and grows larger as the splash builds. Echos from direct hits or near misses will be lost in the target echo, while salvos which straddle the target may envelop the target echo in the midst of the splash echos on the scope, thereby making it impossible to distinguish individual splashes. Range errors can usually be estimated with greater accuracy by radar than by optical spotting, but deflection spotting with radar is sometimes difficult, especially when the error is small. Near misses sometimes merge with and are indistinguishable from the target pip. Consequently, repeated salvos can land with a 2- to 5-mil error which is not separately distinguishable, but they may not be hits. Target practice is used to determine the minimum deflection error that can be detected on a particular radar. When radar is the only means available for deflection spotting, a deflection "rocking ladder" should be used. The order of preference in spotting surface fire is usually accomplished in the following manner: RANGE–radar, air, and visual; and DEFLECTION–visual, radar, and air. In night action, or action under reduced visibility, radar normally spots for both range and deflection.

SPOT PYRAMIDING

The application of a new spot before the effect of a previous spot has had time to become apparent is called spot pyramiding. It can occur only in rapid fire, when the interval between shots or salvos is less than the time of flight plus the spotting interval. In that case, when a salvo lands, there are one or more other salvos in the air. Suppose the spotter makes a spot on the salvo which has just landed. This spot is applied and a new salvo is fired. Then one or more of the salvos which were already in the air lands, and the spotter, forgetting that the previous spot has not had time to show its effect, spots again. This spot is applied to the next salvo fired, with the result that this salvo is overcorrected and will probably miss, as will subsequent salvos until the spotter sees the mistake and spots back again.

The time-of-flight clock signal helps to avoid pyramiding. A button on a mechanical time clock is pressed in the plotting room when the salvo on which a spot is applied is fired. The clock has been preset to ring just before the time of flight of the projectile ends. Before the salvo lands, the mechanism sounds a buzzer. This is then relayed to the spotter via sound-powered phones.

Because spot pyramiding is common and has a disastrous effect on accurate control of fire, the means used to prevent it must be carefully and correctly operated. For example, if the time-of-flight mechanism operator forgets to press the button for a spotted salvo, the spotter, waiting for the signal, may continue to wait even after it becomes apparent that the previous spot was incorrect.

SPOTTING TERMINOLOGY AND MESSAGE PRACTICE

As in other operational communications, there is a prescribed terminology and message sequence for spotting. These are published in fleet operational directives. The examples described in this section show the general practice at the present time.

Surface Fire

For surface fire, only range and deflection are spotted. The correction necessary to bring the fall of shot on target is given in the following terminology sequence.

1. Deflection correction–RIGHT or LEFT, in mils.
2. Range correction–ADD or DROP, in yards.

When no correction in deflection is necessary, only a range spot is made. When no range spot is necessary (regardless of whether a deflection spot is required), the phrase NO CHANGE is used. Typical examples of spot transmissions by telephone are: RIGHT 10, ADD 1,000; LEFT 5, DROP 500; LEFT 10, NO CHANGE; NO CHANGE.

Antiaircraft (AA) Fire

For air targets, corrections to bring the burst on the target are needed in three dimensions. Even well-trained personnel find it almost impossible to estimate errors rapidly in three dimensions. AA spotting is therefore generally limited to correcting for obvious constant system errors.

The proper terminology for spotting in AA fire is as follows:

1. Deflection correction–RIGHT or LEFT, in mils
2. Range correction–ADD or DROP, in yards
3. Height-of-burst correction–UP or DOWN, in mils

NOTE: Spotting should not be attempted while shooting, but only after a run is completed.

Shore Bombardment

In shore bombardment, spots in three dimensions may be necessary. When naval guns are used to support landing operations, joint forces are involved. The Navy, Army, and Air Force have a standardized spotting terminology for joint operations which differs from the preceding information in that all corrections for indirect fire are spotted in yards. Deflection and elevation spots may have to be converted to angular units before being applied to the computer.

Spots in three dimensions are made in the following order:

1. Deflection–RIGHT or LEFT
2. Range–ADD or DROP
3. Height of burst–UP or DOWN

NAVAL GUNFIRE SUPPORT

United States ground forces rely on naval gunfire to support friendly troops along enemy coastlines. This gunfire is delivered from the ship's gun battery in support of troop operations, and related naval and air operations. These operations consist of mine warfare activities, air-sea rescue operations, raids, flack suppression during air strikes, and interdiction of coastal roads, railroads, airfields, and troop assembly areas.

As far as you, as a fire control technician, are concerned, naval gunfire against stationary land targets presents much the same problem as firing at a ship dead in the water (or, with respect to terrain features, at a significant elevation above sea level).

Fire control techniques discussed so far have taken into account only ownship and the target, and the location and velocity of the target with respect to ownship. This is necessary because the featureless seascape provides no reference points. On land, however, there are reference points that can be used to assist in laying the guns on the target, and in preventing fire on friendly troops, vehicles, and installations. In addition, terrain features complicate corrections of the fall of shot. Since computer solutions assume the point of fall to be in the horizontal plane, the elevation of the target above sea level must be considered in the solution. Figure 13-4 illustrates the errors resulting when the range of the land target is taken from a chart and the target's elevation is not considered. Terrain features also affect the size of the pattern in range; a forward slope decreases the dispersion and a reverse slope increases the dispersion. Figure 13-5 illustrates these effects. Gunfire support nearly always involves the use of maps and charts to an extent rarely required in other types of naval engagements.

CLASSIFICATION–NAVAL GUNFIRE SUPPORT

Naval gunfire against land targets may be classified in various ways. The classifications are interrelated; terms from several types of classifications must be used for a full description. These classifications are based on:

1. Effect sought:

a. DESTRUCTION–Deliberate and accurate fire, usually delivered at short range, for the purpose of destroying a target, usually a material object.

b. NEUTRALIZATION–Rapid, fairly accurate fire delivered for the purpose of hampering, interrupting, or preventing enemy fire, movement, or action. Destruction of weapons and personnel is secondary. The effect of neutralization is comparatively temporary; such fire may have to be repeated.

c. HARASSMENT—Sporadic fire delivered during otherwise quiet periods to prevent enemy rest, recuperation, or movement, and in general to lower enemy morale and combat efficiency.

d. INTERDICTION—Fire designed to prevent or curtail the use by the enemy of an area, bridge, airfield, route of communication, etc.

e. ILLUMINATION—Gunfire employing illuminating projectiles (star shells) to illuminate the enemy, to detect their movements, to aid our own observation, or to facilitate our own troop movements.

2. Tactical use:

a. CLOSE SUPPORTING FIRE—Gunfire delivered on enemy targets which, because of their proximity, present an immediate and serious threat to the supported unit. (Close supporting fire may be as close to friendly troops as 300 yards enfiladed, or 600 yards when the target axis is not parallel to the line of fire.)

b. DEEP SUPPORTING FIRE—Gunfire delivered on objectives not in the immediate vicinity of friendly forces, to neutralize or destroy enemy reserves and weapons, and interfere with enemy command, supply, communications, and observation.

c. PREPARATION FIRE—A heavy volume of prearranged neutralization fire,

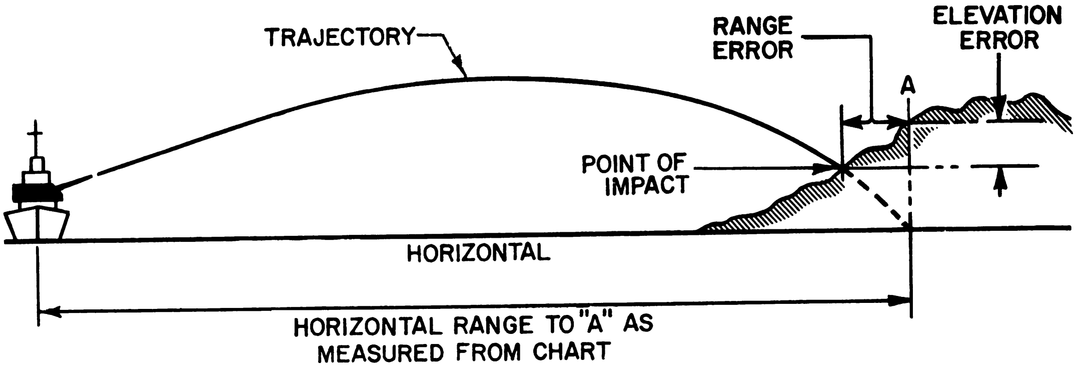


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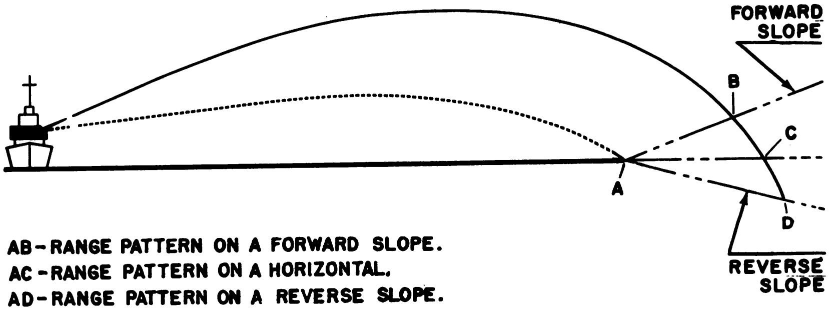
Figure 13-4.—Errors resulting from failure to compensate for target elevation.


FORWARD SLOPE
B
C
A
D
REVERSE SLOPE
AB-RANGE PATTERN ON A FORWARD SLOPE.
AC-RANGE PATTERN ON A HORIZONTAL.
AD-RANGE PATTERN ON A REVERSE SLOPE.

92.67

Figure 13-5.—Effect of terrain slope on the range pattern produced by a ship's guns.

delivered just prior to a landing or a ground attack by friendly forces on enemy positions.

d. COUNTERBATTERY FIRE—Gunfire delivered against active enemy guns and fire control stations for the purpose of silencing the guns.

e. PREARRANGED OR SCHEDULED FIRE—Gunfire formally planned and executed against targets of known location. Such fire is usually planned well in advance and is executed at a predetermined time.

f. CALL FIRE—Gunfire delivered at the request of troop units ashore, or of some spotting agency. Call-fire missions must not be interrupted without permission of the unit requesting the fire, except in case of emergency.

g. OPPORTUNITY FIRE—Gunfire delivered without formal planning or troop request on newly discovered targets, or upon transitory targets. Targets of opportunity may present themselves to the firing ship at any time, but fire must be delivered only with due regard for safety of friendly troops. Ships delivering fire on targets of opportunity close to their own troops require approval of the troop echelon concerned before opening fire. Ships executing deep support missions must assure themselves that the target of opportunity is within their assigned sector of responsibility.

h. RECONNAISSANCE FIRE—Gunfire delivered in areas where camouflaged positions are suspected or in vital areas where natural cover prevents observation and/or gathering of photo intelligence.

i. FLAK SUPPRESSION FIRE—Gunfire used to suppress AA fire immediately prior to and during an air attack on enemy positions.

3. Technique of delivery:

a. DIRECT FIRE—Gunfire delivered on a target by using the target itself as a point of aim for laying the guns or director. Direct fire is usually used on targets which can be seen (by optics or radar) from the firing ship.

b. INDIRECT FIRE—Gunfire delivered on a target which is not itself used as a point of aim for laying the guns or director. Indirect fire is always used on targets not visible from the ship. This fire is spotted by air spotters or shore fire control party spotters assigned for this specific purpose.

4. Type of fire:

a. AREA FIRE—Gunfire delivered in a prescribed area. Area fire is generally neutralization fire.

b. POINT FIRE—Gunfire directed at a definite material target in order to destroy that particular target.

c. ENFILADE FIRE—Gunfire delivered on a target in such a manner that the range pattern of the fall of shot coincides with the long axis of the target (fig. 13-6, view A).

d. DEFILADE FIRE (reverse-slope fire)—Gunfire delivered on targets located behind some terrain feature, such as a hill or ridge, which masks the target (fig. 13-6, view B).

DEFINITIONS OF TERMS

Many terms that may be unfamiliar to you are used in shore bombardment. A brief definition of each of the more common terms is given here.

FIRE FOR EFFECT—A volume of fire of a specified number of rounds delivered on a target after the fall of shot has been placed on the target.

WHEN READY—Cancels AT MY COMMAND.

SHOOT—Command to fire.

SHOT AND STANDBY—SHOT is given when the round is fired; STANDBY is given 5 seconds before the round is to land.

GUN TARGET LINE (GTL)—An imaginary line connecting gun and target. GTL is reported to the spotter when requested prior to delivery of the first round.

READY—Indicates to the spotter that the ship is ready to fire.

ROUNDS COMPLETE—Sent by the ship to indicate that all rounds requested in the fire for effect have been delivered.

DELAY—Used by the ship to indicate that the ship will be unable to provide fire as requested. The amount of delay is indicated in figures understood to be minutes, as Delay 10.

WILL NOT FIRE—Used to indicate the ship is unable to deliver fire as requested.

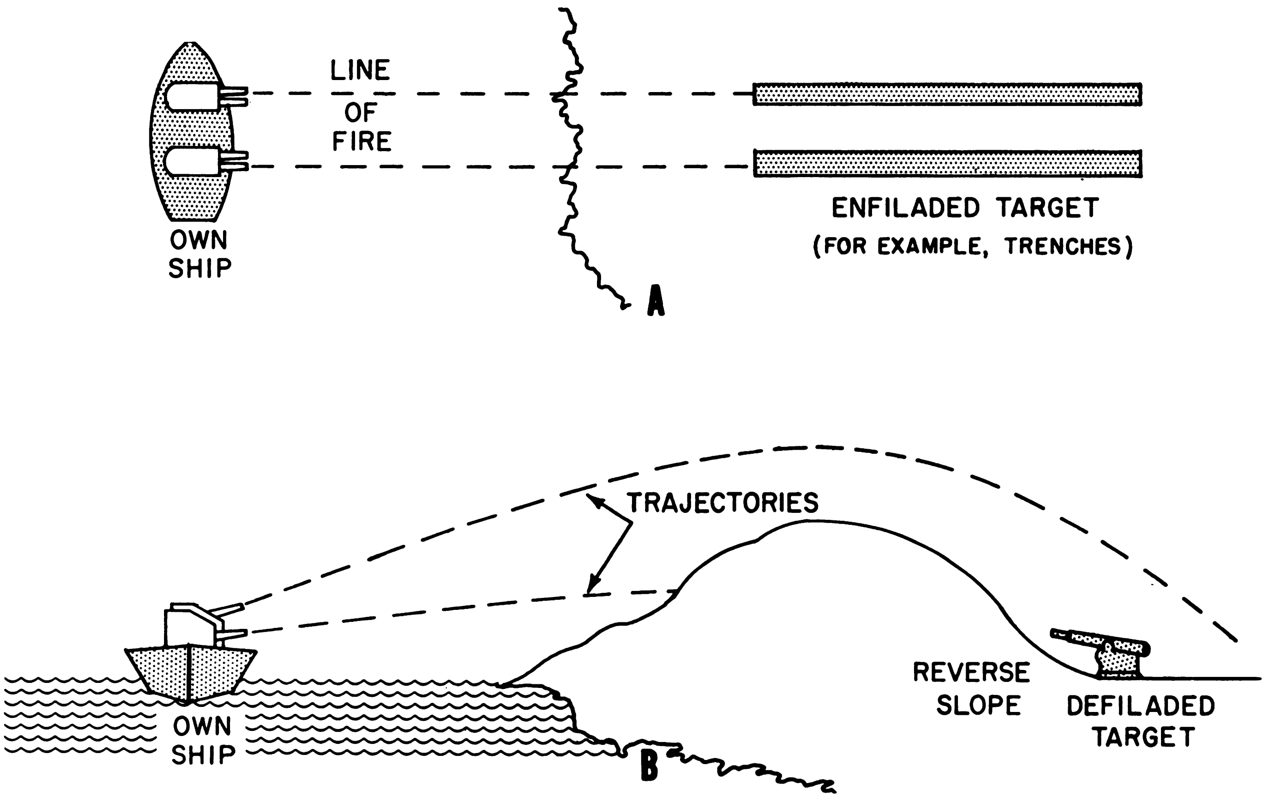


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Figure 13-6.—Types of target.

CORRECTION–To correct an error made by the transmitting agency.

WRONG–Your last transmission was incorrect. The correct version is . . . .

LOST–The round was not observed. The round may have been a dud or out of the spotter's field of vision.

CHECK FIRE–Temporary interruption. Stop firing immediately but continue generating solution.

GO ON–Cancels check fire and is the only term to do so.

FRESH TARGET–Firing is completed on original target. Continue generating solution, another target exists within a 1,000-yard radius. A spot will be given to bring the fall of shot onto the new target.

RECORD AS TARGET–Read the present solution plus range, bearing, and elevation spots and record for future use.

SPOTTING SEQUENCE–Deflection, range, and elevation, are all understood to be in yards, unless otherwise specified. Each may be omitted except the range spot. If no change is wanted in range, the command is REPEAT.

END OF TARGET–An order given to terminate firing at a specific target.

NEGLECT–Term used to indicate last salvo was fired with incorrect data.

DANGER–Friendly toops within 1,500 yards.

DANGER CLOSE–Friendly troops within 600 yards. When danger is included in the call for fire the ship must give the spotter the location where the first salvo is to land (which is at the discretion of the firing ship's CO).

Types of Fuzes

Spotters must also be somewhat knowledgeable of the various types of fuzes, and the ammunition with which they are associated. Such things as when a fuze is activated and the conditions that cause activation are considerations that contribute to effective spotter performance. Following is a list of fuze types and the ammo that they are used with:

1. Quick–(PDF), detonate on impact (HE, and smoke)
2. Time–(MTF), air burst, (AAC, SMOKE, ILLUM)
3. Delay–(BDF) approximately .02 second delay in detonation. (AAC)
4. VT–Bursts occur between 75 and 100 feet when fired against ground targets.

Control of Fire

Another factor in the accomplishment of effective spotting is for the spotter to be knowledgeable of established methods for controlling fire. Remember that actual methods of control are a matter of doctrine. You should refer to the appropriate gunnery publications in order to determine actual procedures. The following methods are, for the most part, acceptable:

1. Will adjust–The spotter controls the fire and is responsible for the adjustment. The ship will:

   a. Report READY and TIME OF FLIGHT prior to firing the first round.
   b. Fire succeeding rounds upon the receipt and application of spots.
   c. Send shot and standby to the spotter on all indirect fire missions

2. Ship will adjust–Ship can see target, direct fire mission. The spotter will play no part in the adjustment of the mission.

3. Will observe–Both spotter and ship can see target. The following is accomplished:

   a. Direct fire mission, the ship will observe and adjust fall of shot on target.
   b. Spotter may also send spots to ship.
   c. The spotter will send error in fall of shot and target damage.

4. Cannot observe–The spotter has information on an important target which cannot be seen. The spotter will:

   a. Send to the ship the best available information as to target location.
   b. Call for a certain number of rounds of fire for effect.

5. At my command (will adjust or will observe)–Spotter will regulate the time of firing of each round or salvo. The following is required:

   a. Ship will report READY for each salvo.
   b. Ship will fire on (fire) order from the spotter.
   c. At my command remains in effect until cancelled by the commands WHEN READY or FIRE FOR EFFECT.

METHODS OF FIRING

In conventional gunfire control (antiair warfare (AAW) and surface fire) the target is visible from the ship, either by radar or optical equipment. As mentioned earlier, this is not always true of shore targets. Much of the firing done by ships in gunfire support missions will be at targets that no one on the ship can see. Fire at a visible target is called direct fire; fire at an unseen target is called indirect fire.

Direct Fire

Targets visible from the firing ship offer the simplest fire control problem to the ship, and their destruction is easier than targets which require indirect fire. Such visible targets include: point targets, counterbattery targets, targets of opportunity, and area targets. When the target can be seen, the director can furnish accurate target bearing and elevation. These, with a present range which can be measured, ensure an accurate fire control setup which should result in early hits. Direct fire is controlled as it would be for fire against enemy ships except that when the ship is providing call-fire support, the spotter will locate the target, order the firing of the first round, and assist the ship in spotting when necessary. The ship will make its own corrections if visibility is good and will end the mission. For a target that is acquired by the ship, control and spotting will be done entirely by the ship.

Indirect Fire: Use of Bombardment Charts

Indirect fire is employed against targets that cannot be seen by the firing ship. Given an accurate chart and knowing the exact position of ownship, it is possible to measure range and bearing to any land target that has been designated in advance, and to hit that target without using the radar or optics.

The ship's position is accurately determined by navigational methods, using positively indentified landmarks, and is plotted on a chart. Since ownship's course and speed are known, future position may be projected ahead along the ship's track by dead reckoning. As in direct fire, because ownship's speed is usually slow (less than six knots), the set and drift of the currents frequently contribute as much movement to ownship as do the propellers. To generate an accurate solution, it is essential to use the total movement of ownship. To ascertain ownship's speed, CIC keeps a continuous plot using navigational methods; after several plots have been made, the distance traveled is measured against time and an accurate value of speed is calculated. This speed is set into the computer by hand as target speed, and ownship's speed is set to zero. Target course is then set in manually as the reciprocal of true ship's course.

Future positions are projected ahead along the ship's track of the drt (dead-reckoning tracker). A future position is chosen, usually 1 minute ahead, and, from this point, bearing and distance to the target are picked off the chart. These values of range and bearing are sent to gun plot and set into the computer manually. When the ship passes the position chosen, the plotter in CIC gives a "MARK" and the time motor on the computer is turned on. The plotted and computed values of range and bearing are then checked by "MARKING" every 15 or 30 seconds. If the range and bearing agree within reasonable limits (50 yards and 1/2 degree), the gun plot is ready to fire. If not, the check procedure is repeated and the bearing and range in the computer are corrected until the set up is correct. Plot is then ready to shoot after reporting the gun target line (the line between the firing ship and the target) to the shore fire control party.

Indirect Fire: Point Oscar Method

This method of indirect fire was devised primarily for ships with fire control systems incapable of correctly generating range and bearing to a designated grid point. Its use, however, even by the newest ships, is advantageous under certain conditions, such as when no shore spotter or air spotter is available for observing the fall of shot. The method requires a visible point of aim–designated "Point Oscar"–near the target, as well as the accurate location of the target and Point Oscar on a map.

In practice, the director line of sight is kept continuously trained and ranged on the point of aim (Point Oscar) to give a continuous range and bearing solution to this point. Salvos are initially fired at Point Oscar as a check on the gun ballistic. As soon as the point of impact has been spotted to hit, range and deflection spots necessary to hit the invisible targets are applied.

Since the motion of the firing ship continuously changes the values of the offsets from the point of aim, frequent changes in these offset spots must be made to ensure hitting the target. This problem is illustrated in figure 13-7. One way to continuously determine correct range and deflection spots is to use a small transparent overlay on which are inscribed 100-yard squares drawn to the same scale as the chart. With the center of the gridded overlay on Point Oscar, and the grid lines oriented to the direction of the line of sight from the ship, range and deflection spots to hit the designated target may be read directly from the grid overlay.

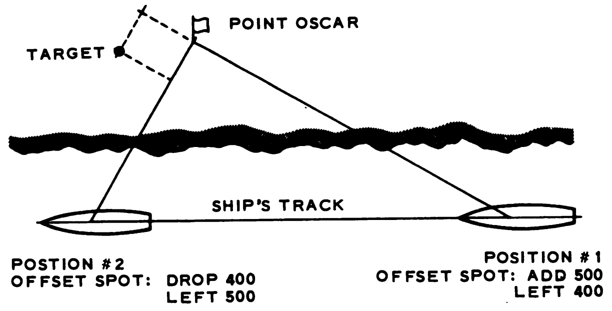

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Figure 13-7.—Point Oscar method of indirect fire, showing necessity for continuous changes in offset spots to hit target.

Indirect Fire: Radar Beacon

The radar beacon is a portable transmitter-receiver. Set up by the shore fire control party, it is capable of emitting a characteristic signal when keyed by the transmitted pulse of the ship's fire control radar. This signal is different in frequency from the transmitted pulse to eliminate the normal echo returns from the shore. The signal is received by the fire control radar when the radar receiver has been tuned to receive the beacon frequency. Extremely accurate ranges and bearings to the beacon may be obtained. It can be tracked manually or in automatic radar control.

The radar beacon is used primarily to aid in the delivery of accurate naval gunfire under all conditions of visibility and to eliminate the errors of normal navigational plotting, using landmarks and other visual navigational aids.

Indirect Fire: Defiladed Targets

Targets which are located on the far slope of a hill or ridge between the firing ship and the target present a particularly difficult problem to the flat trajectory of naval gunfire. The projectile must clear the crest of the hill, but fall steeply enough to hit the target beyond. In this situation (defiladed target), an angle of fall must be chosen which is greater than the angle of the reverse slope. Two solutions are then available. The ship may either increase the range or it may use reduced-velocity charges at a shorter range to obtain this selected angle of fall. Figure 13-8 illustrates this problem and its solutions. A is the trajectory produced by standard service charges and is too flat; B is the trajectory which can be obtained by using reduced-velocity charges; and C is the trajectory which can be obtained with standard service charges by increasing the range.

If the ship must fire over friendly troops on an elevated position between the firing ship and the target, it is necessary to determine target elevation, the elevation of the troop position, and the difference between the two.

SPOTTING IN GUNFIRE SUPPORT

The principles of spotting discussed earlier in this chapter apply in gunfire support spotting from the ship, but procedures are different when spots are made by a fire control party ashore. A spotter ashore must be located where the best observation of the fall of shot can be seen. Usually, this requires the spotter to be as close as possible to the target. This can present the spotter with the very serious problem of survival. The spotter also has an alignment problem. Spots made by an observer aboard the firing ship are naturally oriented to the line between the firing ship and the target (called the gun target line or GTL). Spots made from aircraft can be readily oriented to the gun target line, since both the gun and the target are normally within the aircraft observer's field of vision. But, spotters ashore are frequently unable to see the firing ship and, so long as they are required to make their reports in relation to the gun target line, the value of the information sent by the spotter to the ship is limited.

To simplify this problem for the spotter, the target grid system, for use in spotting the fall of

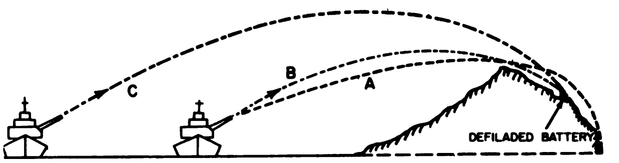

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Figure 13-8.—Problem of hitting a defiladed target.

shot on land, is used. The target grid system is part of the standard spotting and general gunfire support procedure for use within the naval service.

The target grid system permits the observer to spot the fall of shot just as it is seen along own line of sight to the target (called the observer target line of OTL), regardless of the position of the firing ship and of the gun target line. The procedure is briefly outlined as follows (fig. 13-9):

1. The observer's call for fire must give the bearing from the observer to the target (direction OTL in the illustration).
2. The observer makes all observations and corrections with respect to the observer target line (OTL).
3. The ship's CIC or plotting room crew converts the corrections of the observer to corrections with respect to the gun target line (GTL).
4. The plotting room crew introduces into the computer the spots corrected to the gun target line.

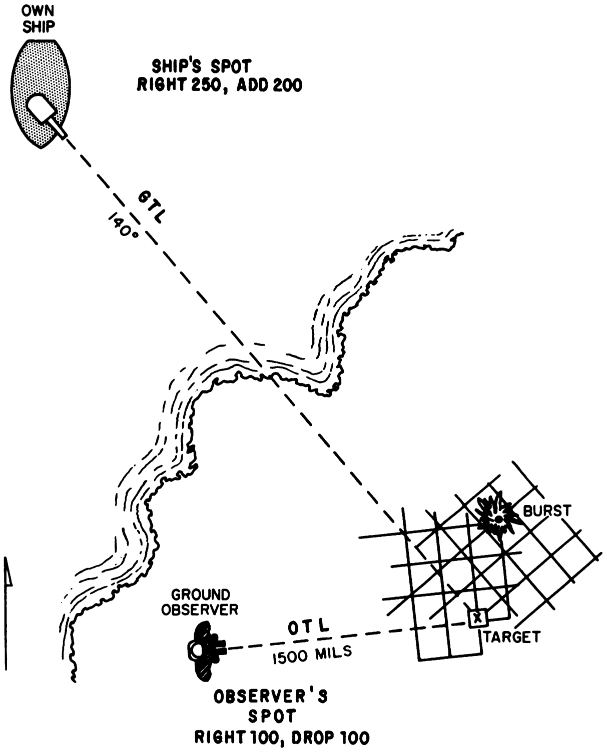

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Figure 13-9.—Target grid spotting problem.

SUMMARY

The fundamentals of spotting that have been presented in this chapter should give you some understanding of spotting as accomplished in naval gunfire. It also should point out the fact that practice is necessary in order for you to keep and advance your proficiency in this area.

Naval Gunfire Support is a very large field and has only been touched upon very briefly in this chapter. The knowledge that you have acquired, plus the publications that are available on the subject should help you to know and to understand the requirements that are necessary for a complete and reliable gunfire support team on any ship on which you may be serving.

CHAPTER 14

UNDERWATER FIRE CONTROL

In a discussion of underwater fire control, it is necessary to have a basic understanding of the submarine and its weapons (fig. 14-1).

There is one primary reason for building a warship that is capable of submerging—to get within striking distance of a target without being detected. With the advent of nuclear propulsion, a more efficient hull design, and more advanced target detection devices and torpedos, the submarine is a more lethal weapon system than ever before. The submarine's torpedo tubes are fixed, and cannot be trained or elevated. The ship, therefore, is part of the weapon launching system. But the torpedo can steer a course to intercept the target, and the submarine does not have to be at a particular point in order to hit the target. Thus, the submarine is free to maneuver in accordance with the tactical situation.

The torpedo is a self-propelled underwater weapon that carries a destructive charge to its target. A torpedo may be thought of as an underwater guided missile, having a guidance and control system that automatically steers the torpedo and controls its depth. Torpedos, by changing their course, depth, and speed after launch, can actively attack targets. The underwater fire control problem is very important in getting the torpedo to its target, but does not require the same exactness that was necessary with the old, straight running torpedos. The torpedo must, however, still be put in the vicinity of a target so that it is capable of conducting its attack.

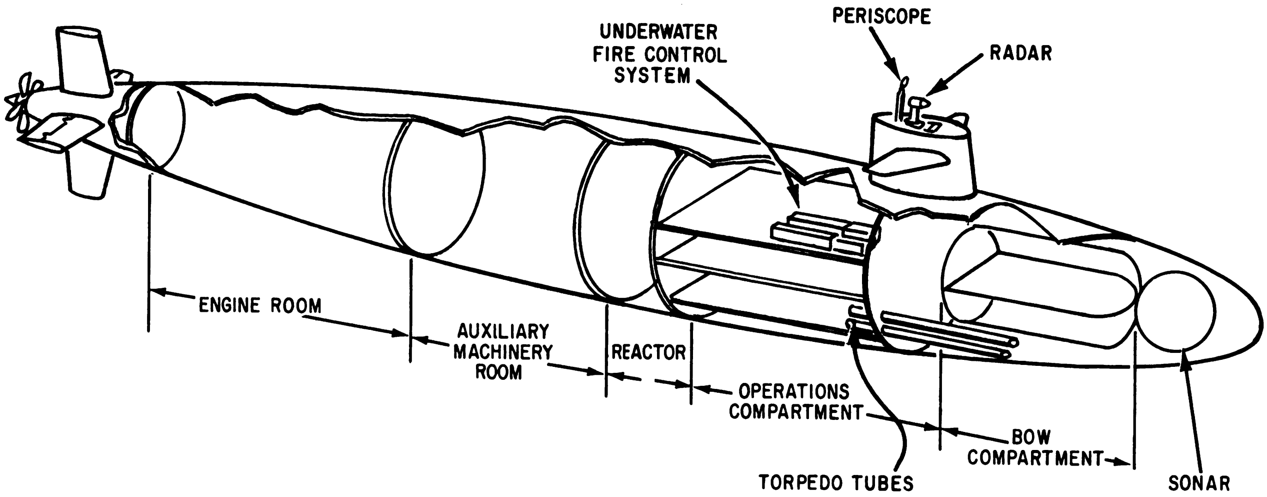

Figure 14-1.—Typical SSN submarine.

UNDERWATER FIRE CONTROL PROBLEM

The first step in the solution of any fire control problem is the detection and location of the target. As mentioned earlier, the basic reason for building a submarine is to get within striking distance of a target without being detected. But at the same time, the submarine must be able to locate the target while submerged. A submarine has optical, radar, and sonar target detection equipment, as shown in figure 14-1.

PERISCOPE

The function of a submarine's periscope is to give a view of the surrounding surface area while the submarine remains submerged. The periscope is raised above the surface of the water while the submarine remains just below the surface to reduce the possibility of its own detection. When a submarine is using its periscope, it is readily apparent that its depth is limited to the length of the scope. This depth is called periscope depth. Since it is virtually impossible to see any great distance through water, the periscope must extend above the water to be used. Even though the part of the periscope that projects above the surface is made to be as inconspicuous as possible, a raised periscope can be detected visually or by radar.

To its advantage, a periscope can accurately measure the range and bearing to a target. Moreover, with visual detection, identification and classification as a friend or foe is easier, and may be made without alerting a possible target to the presence of the submarine.

RADAR

A submarine radar is functionally identical to its counterpart in a surface ship. There are, however, some disadvantages to a submarine using radar. The presence of a submarine with its radar transmitting can easily be detected, because the radar broadcasts a telltale electromagnetic signature that can be read and identified. Therefore, the use of radar reduces a submarine's concealment. Moreover, the radar antenna must be above the surface of the water in order to operate, since water is a poor conductor of the radar's rf energy. Therefore, like the periscope, radar operation limits the submarine's depth.

SONAR

There are two general classes of sonar—active and passive. Active sonar transmits underwater sounds that strike targets and are returned as echoes. Accurate range and bearing can be measured by active sonar. Passive sonars do not transmit, but merely listen for sounds produced by a target. Accurate bearing and estimated range information can be obtained from passive sonar. Obviously, active sonar is more accurate, but passive sonar is safer to use.

Sonar equipment is used most frequently for the detection and tracking of targets, since it can be used at any depth at which the submarine is located. Its ability to be used passively is another factor in its favor.

Sonar equipment is operated and maintained by the sonar technician. But, an overview of sonar theory is included in this chapter so that you can better understand the underwater fire control problem and its interconnection with the sonar equipment.

Sonar operates on the principle of the propagation (transmission) of sound waves through the water. Unlike rf energy from a radar set, which travels at a constant speed and in a straight line, sound waves through water are deflected and changed in speed by certain water conditions.

Density

When a sound wave passes through a medium, it is transmitted from particle to particle. If the particles are loosely packed (as they are in fresh water as compared with sea water), they have a greater distance to move to transmit the sound energy. In doing this, time is consumed, and the overall result is a slower speed of sound in a less dense medium.

Density is why a sound wave travels through air at one speed, through pure water at another speed, and through sea water at still another speed.

Speed of Sound in Seawater

The speed of sound wave travel through the water is controlled by three factors (conditions of the sea).

1. Temperature, which takes the form of slopes and gradients
2. Pressure, caused by increased depth
3. Salinity, or the salt content of the water

TEMPERATURE.—Temperature is by far the most important of the factors affecting the speed of sound in water. The speed of sound increases with increasing temperature at the rate of 4 to 8 feet per second per degree of change, depending on the temperature. Inasmuch as the temperature of the sea varies from freezing in the polar seas to more than 85°F in the tropics, and may decrease by more than 30°F from the surface to a depth of 450 feet, it is clear that temperature is the most important consideration. Remember: The speed of sound increases when the temperature of the water increases. Sound travels at a speed of approximately 4800 feet per second through sea water with a temperature of 39°.

PRESSURE.—Sound travels faster in water under pressure. Pressure increases as depth increases, so the deeper a sound wave travels, the faster it travels. This effect on the transmitted sound of current sonar equipment, however, is rather small.

SALINITY.—Sea water has a high mineral content. Salt content is spoken of as the salinity of the water. The weight of the higher density sea water is about 64 pounds per cubic foot; that of fresh water is about 62.4 pounds per cubic foot. This variation is the result of the salt content in the sea water.

The overall effect of increasing the salinity is to increase the speed of the sound. This means that when sound passes through water that varies in salinity, it travels faster in the saltier water.

Depth and Temperature

Except at the mouths of great rivers, where salinity may be a determinant, the path taken by sound is determined by the pressure effect of depth and temperature. The pressure effect changes the density of the sea water, which in turn will vary the speed of the sound waves. The change in density also causes the sound waves to be refracted and reflected.

REFRACTION.—If there were no temperature differences in the sea, the sound wave would travel approximately in a straight line, because the speed of sound would be roughly the same at all depths. As indicated in figure 14-2, the sound would spread and weaken at a relatively constant rate.

Unfortunately, however, the speed of sound is not the same at all depths. The velocity of sound in sea water increases from 4,700 feet per second to 5,300 feet per second as the temperature increases from 30° to 85°F. Salinity and pressure effects on sound speed usually are unimportant in relation to the effects commonly produced by temperature changes in the sea. Because of the temperature differences, the sound does not travel in a straight line. Instead, it follows curved paths, resulting in the

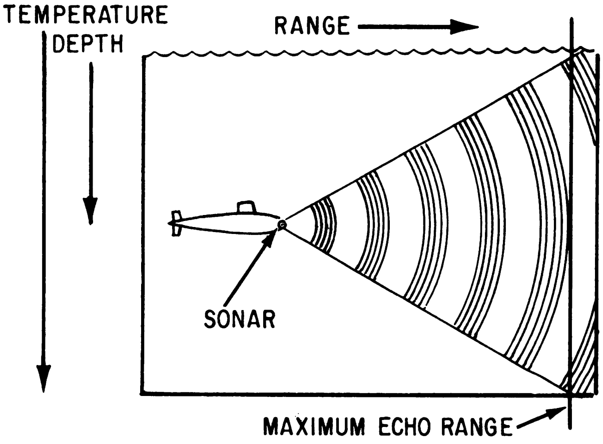

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Figure 14-2.—Sound travel in water of constant temperature.

bending, splitting, and distortion of the directed sound.

Assume that a sound wave is transmitted in the form of a beam. When the beam of sound is bent, it is said to be refracted. A sound beam is refracted when it passes from one medium in which its speed is high (such as warm water) into one in which its speed is low (such as cool water). A sound beam bends away from levels of high temperature and high sound velocity, and bends toward levels of low temperature and low sound velocity. Figure 14-3 gives a good idea of refraction.

REFLECTION.—Reflection of sound waves takes place when there is a change in density. This normally occurs at the point where another medium gets in the way of a sound wave. For instance, a sound wave traveling through sea water is almost entirely reflected at the boundary between the water and the air (sea surface). The speed of sound in sea water is about 4 times greater than the speed of sound in air, and the density of the water is more than 800 times greater than that of air. The result is that most of the sound wave is reflected downward from the sea surface.

Similarly, when a sound wave traveling through sea water strikes a solid object like a submarine, the difference in the density (and sound velocity) in the two mediums is such that all but a small part of the sound beam is reflected. That portion of the beam that strikes surfaces of the submarine perpendicular to the beam is reflected directly as an echo. Figure 14-4 shows this action.

An experienced sonar operator can locate the target with an accurate range and bearing when provided with correct information on the surrounding water conditions. This location is sent to the underwater fire control system as target present position.

Doppler Effect

The Doppler effect pertains to the change in frequency between the source of the wave motion (transmitter) and the observer of the wave motion (receiver) when the distance between the transmitter and the receiver is changing. That is, if either the transmitter or the receiver is moving toward or away from the other, the received frequency will not be the same as the transmitted frequency.

An experienced sonar operator can interpret the change in pitch of the audio echo signal. When the echo frequency (pitch of the sound) is higher than the transmitted frequency, the operator calls it "Up Doppler." This indicates that range is closing. If the echo frequency is

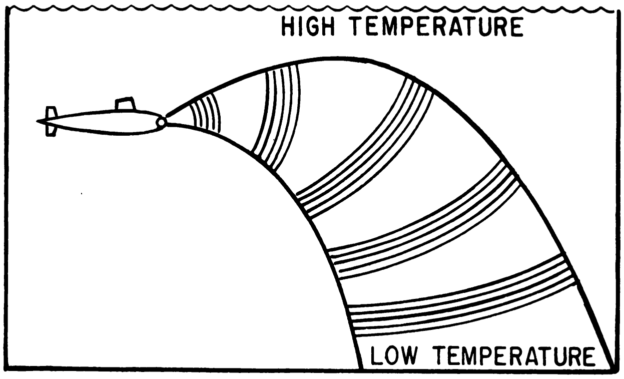

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Figure 14-3.—A refracted sound beam.

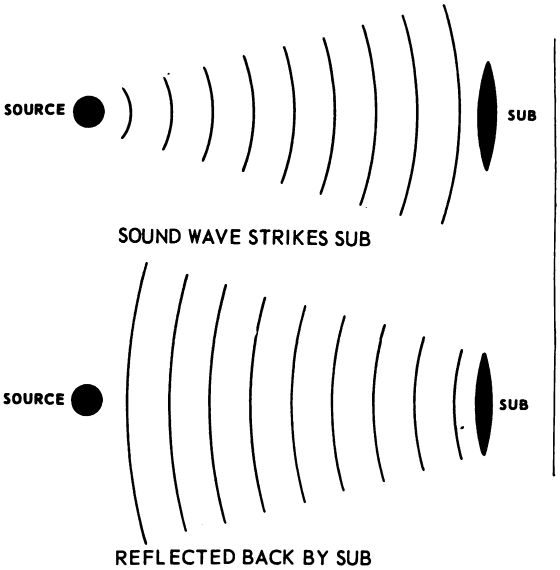

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Figure 14-4.—Sound reflection from a submarine.

lower, the pitch is lower and the operator refers to it as "Down Doppler," which indicates that range is opening. If there is no change in pitch, the operator calls it "No Doppler" and knows that there is no range rate.

Active Sonar Systems

Active sonar systems are comparable with pulse radars. Both transmit a pulse containing a high level of energy, and depend on the echo principle to detect targets. In each case, the energy is considered to travel in a linear manner with respect to time. Thus, range is a function of the transit time of the energy returned as an echo. Bearing is determined by measuring the direction from which the echo has returned.

Passive Sonar

Passive sonar depends upon noises generated by a target as its source of sound, instead of reflected echoes from a transmitted pulse. A passive sonar does not transmit. Passive sonar is so efficient that a sound many miles away may be detected and identified, and its source tracked.

NOISE SOURCES.—There are many natural noise sources in the sea, many of which are known. An experienced sonar operator can distinguish between the natural and background noises and those generated by a ship.

SHIP NOISES.—A ship's motion through the sea produces both flow and propeller noises. The flow noise is caused by the disturbance of the water as the ship moves through it. Propeller noise is produced by cavitation; that is, gas bubbles formed by the high speed rotation of the propeller. Machinery noise is produced by the ship's main propulsion plant and by the large number of machines throughout the ship. Of the noises generated by a ship, the propeller noise is normally the most pronounced and the first detected by a passive sonar.

ARRAY SONAR.—Today's passive sonar utilizes a hydrophone array (fig. 14-5). A hydrophone is an instrument for listening to sound through water. It consists of a number of single line hydrophones connected together. They are mounted to follow the shape of the submarine bow.

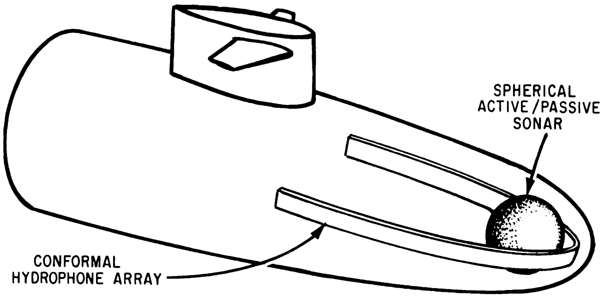

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Figure 14-5.—Array sonar.

Corrections to Sonar Observed Quantities

The fire control problem is based on the position of the target as measured from the system's reference point. A submarine's reference point is normally one of the periscopes. The quantities describing target position are corrected to the optical line of sight from the reference scope. Since the sonar equipment and the torpedo tubes are not located at the reference point, the same types of parallax problems exist that were described in the gun fire control problem. (These problems will not be restated here.) However, when sonar is used to determine target position, additional corrections are necessary.

The sonar is not pointed at the actual position of the target because of the curvature of the sound beam. Therefore, the correct present target position quantities must be computed from the available sonar measurements. In the computations, two additional positions are encountered—apparent target position and past target position.

Apparent target position is the position from which the received sound signal appears to come; that is, the position of the target as indicated by the sonar. It is different from present target position because of target travel during the time it takes the sound to travel between the target and ownship, and because of the refraction of the sound beam.

Past target position is the position from which the sound beam actually comes; that is, the target when it originates the sound or reflects the echo. It differs from the present position because of target travel during the time it takes the sound to travel between the target and ownship, and it differs from apparent position because of the refraction of the sound beam.

SONAR BEARING CORRECTION.– Consider the corrections that are necessary when target bearing is measured by a passive sonar. To simplify the explanation, assume that the hydrophone array is located at the reference point. This will eliminate the parallax correction due to the baselength aboard ownship. A passive sonar normally measures bearing by the sound from the target's propeller. Hence bearing is measured to the target's stern, rather than to its middle as optical bearings are measured. Correction for the curvature of the sonar beam is made in the sonar equipment, and therefore will not be covered here.

Figure 14-6 shows target movement, L1, during the time it takes the sound to travel between the target and ownship. This time interval, T1, is equal to the range divided by the speed of sound. Assume that the speed of sound under the existing conditions of the sea is 4,950 feet per second.

If a rate in yards per second is required, divide the constant by 3. Call the speed of sound SS, and assume that it is in the correct unit of measure. Therefore:

$$T1 = \frac{R}{SS}$$

The line L1 is equal to the displacement between the source of the sound and the position of the target at the reception of the sound. (The line has been greatly exaggerated in the diagram.) Therefore:

$$L1 = DMt \times T1 \text{ or } \frac{DMt \times R}{SS}$$

where DMt is target speed.

The distance between the point on the target from which sonar bearing is measured and the point from which it should be measured is shown by the line L2. The difference between

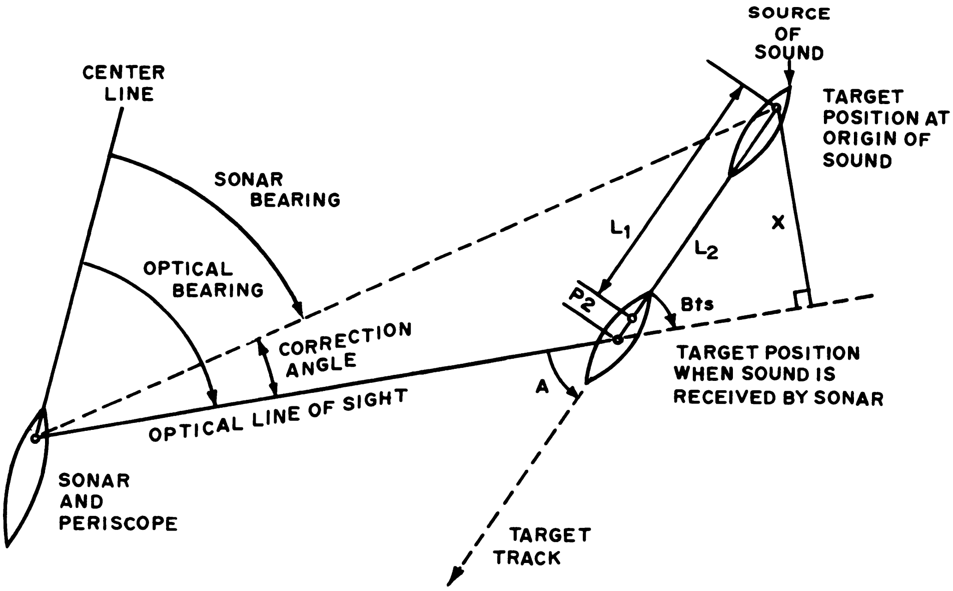

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Figure 14-6.—Correction to sonar bearing.

L1 and L2 is the distance P2, which is equal to half the length of the target. The addition of P2 brings the point from which bearing is measured to the middle of the target (MOT).

The correction to sonar bearing is proportional to the component of L2 perpendicular to the optical line of sight. The line X is drawn perpendicular to the optical line of sight and connects it to the source of the sound. Thus, a right triangle is formed whose hypotenuse is L2. Use target angle Bts to solve for X.

$$\sin Bts = \frac{X}{L2} \text{ or } \frac{X}{P2 + \frac{DMt \times R}{SS}}$$

hence,

$$X = \left[\frac{DMt \times R}{SS} + P2 \quad \sin Bts\right]$$

Now compute the correction to sonar bearing. Use the right triangle whose hypotenuse is the sonar bearing line. The correction is equal to the angle whose tangent is equal to the quantity X over the optical range to the target. Since the change in range during T1 is negligible, use the symbol R for both optical and sonar range. Therefore:

$$\text{Correction angle} = \tan -1 \ \frac{X}{R}$$

The symbol, tan -1 stands for the angle whose tangent is equal to the values that follow it. Substituting for the quantity X gives

Correction angle = tan. -1

$$\left[\frac{(P2 + \frac{DMt \times R}{SS}) \sin Bts}{R}\right]$$

The addition of this corrective angle to the bearing measured by a passive sonar provides the correct target bearing. If an active sonar were used, the value of P2 would not be needed in the formula. Active sonar measures bearing to the MOT.

Observed Quantities

The periscope, radar, and active sonar can accurately measure the target's present position; but, to reduce the possibility of a target detecting ownship's position, these devices are used sparingly. Thus, the fire control system receives target range and bearing intermittently. When a measurement of target position is made, "mark" signals are transmitted to indicate that a correct present range or bearing is available. Only when a mark signal is present is this information inserted into the fire control system.

PASSIVE SONAR MEASUREMENTS.—Target range cannot be measured by a passive sonar, but range can be computed from the bearing rate and target course and speed. An experienced sonar operator can provide a target speed of usable accuracy by counting the revolutions of a target's propeller. The sound received from a target is modulated by the propeller revolutions. Obviously, there is a relationship between propeller revolutions and target speed.

Look at the problem of determining the range to a target when only bearing can be measured directly. First, eliminate ownship's bearing rate by assuming ownship's speed is zero. Three bearing measurements are taken at different time intervals and plotted with respect to ownship (fig. 14-7). Since range is unknown,

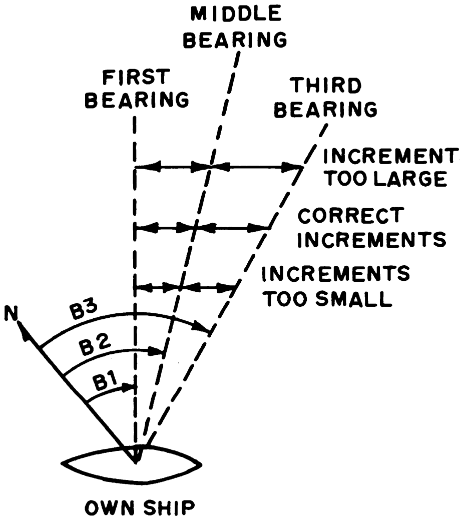

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Figure 14-7.—Solving for range.

the length of the lines is unknown. But, there are two additional factors: the increments of bearing change and the time period in which the changes occurred. The formula to compute the increments is:

$$\text{Increments} = \frac{\text{bearing rate x time}}{\text{range}}$$

The target bearing rate is equal to target speed times the sine of target angle. You should be familiar with this type of problem, and with the fact that the bearing rate is inversely proportional to range. Thus, there is a relationship between a change in bearing and the range to a target.

Now, the bearing increments are known; but there are an infinite number of combinations of target course, speed, and range which will satisfy the conditions in the formula. If any one of these quantities is known, there is only one reasonable combination of the two remaining quantities which will produce the correct increments. Therefore, when the target speed measured by the sonar operator is inserted into the formula, a reasonably accurate target course speed, and range can be produced. The bearing increments are continuously checked to refine these quantities. In other words, continue to check the slope of the observed bearing line against the computed slope of the bearing line. The target must remain on a constant course and speed during this problem. If the target maneuvers, analysis of its motions must be started again. The sonar operator can detect when a target is maneuvering.

Target course and speed have been computed to solve for range. These quantities are unknown values in the fire control problem. Thus, even when an active type of target detector is used and range is known, target motion is still analyzed in this manner. Range is inserted into the formula to obtain the computed course and speed. These values are transmitted to the position keeper to start the tracking problem.

GEOMETRY OF THE UNDERWATER FIRE CONTROL PROBLEM

The underwater fire control problem, like all fire control problems, can be divided into two major sections—the relative motion section and the ballistic section. The relative motion section does not deal with the weapon, but solves a tracking problem that basically consists of position keeping between the firing ship and the target. This section of the problem involves detecting the target, measuring its position, determining the direction and rate of its motion, and correlating ownship's motion with the target's. The outputs of the relative motion section are a continuous measurement of target position and the relative motion rates.

RELATIVE MOTION PROBLEM

The relative motion problem is solved in what is called the position keeper section of the fire control system. The main function of the position keeper is to supply the ballistic computer with continuous information on present target position and motion. The inputs to the position keeper are:

1. Target position—range and relative bearing
2. Target motion—target course and speed
3. Ownship's course and speed

Ownship's course and speed are received continuously. Target position data, however, is normally received intermittently from a selected target detection device. When a correct value of target range and bearing are being transmitted, a mark signal is sent to the position keeper.

The position keeper resolves the known values of ownship's course and speed and the estimated values of target course and speed to obtain the relative rates of motion with respect to the line of sight. A relative range rate along the line of sight and a relative bearing rate across the line of sight are established. The rates are integrated with time to produce increments of relative motion. The generated increments are added to the initial target position to obtain the computer range and bearing.

The computed values are compared with the observed values when a mark signal is received. If the computed and the observed values are not in agreement, target course and speed are adjusted by a process called rate controlling. Rate controlling can be done either manually or automatically, but it is continued until the computed values change at the same rate as the observed values.

This should sound familiar, since it is identical to the relative motion problem in the gun fire control problem. Therefore, the same ground will not be covered again by going into the details here.

BALLISTIC PROBLEM

The ballistic problem (getting the torpedo from ownship to the target) for underwater fire control is quite different from that of gun fire control. As can be imagined, a torpedo running through water reacts differently than a projectile soaring through the air.

A submarine may have three classes of torpedos aboard: preset straight-running, preset programmed, and wire guided. The solution to the preset straight-running torpedo problem is: torpedo gyro angle, torpedo run, and impact point. The solution to the preset programmed and wire-guided torpedo problems are modifications to this information. Therefore, this discussion starts with the straight-running torpedo problem. But first, the fire control symbol system to be used must be established.

The symbols for underwater quantities are listed in Volume 2 of OP 1700, "Standard Fire Control Symbols for Underwater Related Quantities."

The following is a list of the more common symbols and quantities, including those needed in the study of this chapter:

Symbol	Quantity
B	Relative target bearing
B8	Solution angle
Bts	Target angle
c (Hm)	Enabling run
c (Hm) j	Enabling run offset
DCo	Rate of change of ship's course
DMt	Target Speed
G	Gyro angle
Hm4-6	Torpedo straight track run distance
Hm6	Torpedo run
Hvm	Torpedo running depth
j (Cm)	Latitude correction
jm (Hm)	Emergence speed factor
jte (Um)	Torpedo speed correction
jv (Hm)	Depth change run difference
Ly	Proofing latitude
Ly2	Firing latitude
q (Hm)	Shift along the target track
R	Range
R3	Reach distance
Sq (Hm)	Linear spread
T2-6	Time of run
Uu	Torpedo speed
Ym	Turning radius

The ballistic problem for the torpedos is solved in what is called the angle solver section of the fire control system. The angle solver develops the torpedo control orders of gyro angle (G) and torpedo run (Hm6). These orders cause a preset straight-running torpedo to follow a course that intercepts the target at a predicted impact point. The inputs to the angle solver include target data, ownship data, and torpedo ballistic data.

It should be brought out that an underwater fire control system is an integral part of a weapon system, connected at one end to the various target sensors and tactical operational devices, and at the other end to the weapons and their launching systems. The weapon system is highly flexible to take advantage of a submarine's characteristics and to make the system adaptable to the tactical situation that may be encountered. In addition, the system's flexibility allows a diversified weapon load. The following is a list of the most likely sources of the inputs to the angle solver. Keep in mind that the data is not rigid and depends upon the situation, the type of installation, and the weapon to be fired.

Target Data

Target data inputs to the angle solver consist of relative target bearing, range, target angle, and speed. The angle solver normally receives a smooth generated range and bearing along with the computed target angle and speed.

Another source of target data is from manual plots which are used to interpret the data measured by the target sensors. Thus the target data may be manually inserted into the angle solver.

Ownship Data

Ownship data inputs to the angle solver consist of ownship's course and the rate of change of ownship's course from the gyro compass, ownship's motion, north and east, from the dead reckoning analyzer/indicator, and ownship's depth from the depth detector.

Torpedo Ballistics

Each type of torpedo is test fired many times under standard ballistic conditions to determine a theoretical or standard trajectory. The location of the test firings is called the torpedo proofing latitude. The torpedo run is made at an ordered standard running depth and it is assumed to travel at its designed running speed from the instant of firing. A standard seawater temperature of 62°F is assumed. From the results of these firings a standard torpedo run is established, and the effects of variations from standard ballistic conditions are computed.

The ballistic factors in the torpedo problem are: reach distance, R3; radius of turn, Ym; tactical speed, Uu; running depth, Hvm; and proofing latitude, Ly. The reach distance and the radius of turn for each torpedo are constant, and are explained in the prediction problem. There may be a slight difference between the radius for a right turn and for a left turn, due to the direction of rotation of the torpedo's propellers. This is considered in the angle solver, but is not covered in this discussion, since in either case the radius is constant.

The ballistic factors result in the difference between the actual torpedo run and the theoretical or standard torpedo run. They affect either torpedo speed or the direction of its run. Corrections to the ballistic factors are: torpedo tactical speed, jte (Uu); emergence speed factor, jm (Hm); depth change run difference, jv (Hm); and torpedo firing latitude, Ly2.

TORPEDO TACTICAL SPEED.—All predictions in the problem are based on the time it takes the torpedo to arrive at the impact point. Any change in torpedo speed must be compensated for in the computation. The torpedo has two speed settings—high and low—that adapt the torpedo run to the tactical situation. The selected speed is called the torpedo's tactical speed, Uu. Each type of torpedo has a designed running speed. This speed is determined at a particular running depth and at a standard seawater temperature of 62°F. A variation in either of these conditions will change the pressure and density of the water through which the torpedo is traveling, and will, therefore, affect its speed. The correction to the torpedo tactical speed, jte (Uu) is an input to the angle solver to compensate for changes in the tactical speed of the torpedo.

The running speed of a torpedo may vary with the depth of its run. Torpedo speed is based on running at a specified proof depth, Hvm. When set for any other depth, the torpedo's speed must sometimes be corrected. The correction to speed for depth is called jv (Uu).

EMERGENCE SPEED FACTOR.—The standard torpedo run is based on the fact that the torpedo speed is constant throughout its run. If a torpedo emerges from the torpedo tube at a speed that is different from the standard speed, a correction must be made. If, for example, its emergence speed is greater than its running speed, it will go a greater distance than initially computed. This additional distance must be allowed for in the computation. This correction is called jm (Hm).

Directional Correction

A gyro furnishes the directional reference for the torpedo. Gyros were covered in chapter 4. As you know, the amount of apparent drift (precession) of a gyro is a function of latitude. Therefore, if there is a difference between the torpedo's proofing latitude, Ly, and its firing latitude, Ly2, a correction, j(Cm), is necessary.

TORPEDO SALVO PATTERN.—Sometimes it is desirable to fire torpedoes in salvos. In this case they are not all fired at the same point. To allow for errors in the knowledge about the target, or for possible changes in target course and speed, the torpedoes are fired in a pattern. One such pattern is a linear spread. A unit of linear spread is selected for each torpedo. A number of units are selected either fore or aft. Look at figure 14-8. Three impact points are shown. The center impact point is the one for no linear spread. Liu on the diagram represents the distance selected for a unit of spread. The impact point farther along the target track represents the impact point with two units of spread forward in the computer. Notice that linear spread is put in along the target track. Both gyro angle and torpedo run are changed by linear spread. Linear spread clearly will increase hit probability if there is an error in estimating target speed.

Another type of salvo pattern is called angular spread. As with linear spread, a unit of spread is selected. Then, for each torpedo, a number of units is selected either right or left. (See figure 14-9.) The spread angle is added to or subtracted from the gyro angle after a solution has been reached. As a result, the torpedo run (U) is unchanged. Angular spread is a correction across the torpedo track. Linear spread is a correction along the target track. Either correction is intended to allow for errors in the knowledge about the target or for errors in the torpedo.

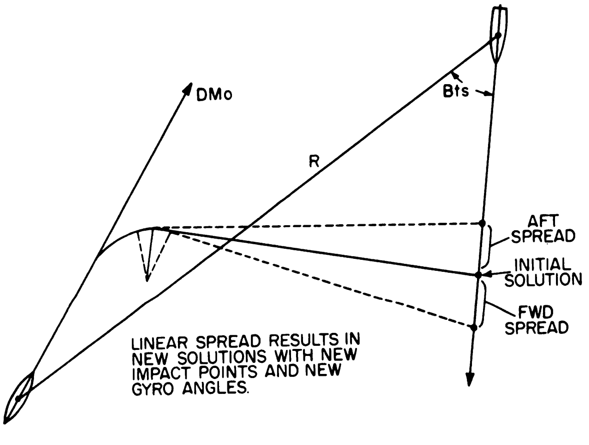
TORPEDO ORDERS

As mentioned earlier, the torpedo is a self-propelled underwater weapon and is capable of changing its course, depth, and speed after launch. Unlike the projectile fired from a gun mount which cannot be controlled after firing, the torpedo can be ordered to change its running characteristics after launch.

Today's submarine has a choice of many types of torpedos, each designed for a specific purpose. The three main classes of torpedos are the preset straight-running, preset programmed, and wire-guided.

PRESET STRAIGHT-RUNNING TORPEDO

The computation for the preset straight-running torpedo orders is based on the simultaneous solution of two equations. The equations are used to calculate the coordinates



LINEAR SPREAD RESULTS IN NEW SOLUTIONS WITH NEW IMPACT POINTS AND NEW GYRO ANGLES.

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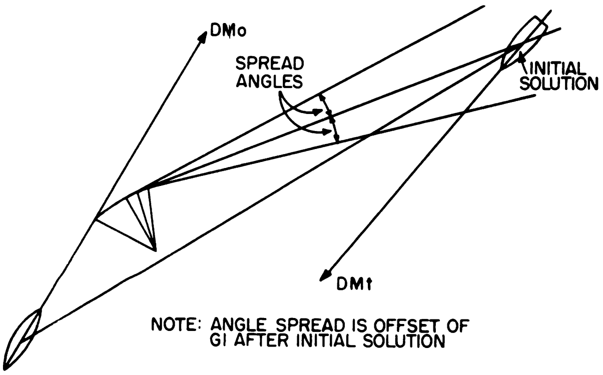
Figure 14-8.—Preset torpedo with linear spread.



NOTE: ANGLE SPREAD IS OFFSET OF GI AFTER INITIAL SOLUTION

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Figure 14-9.—Preset torpedo with angular spread.

of the center of the torpedo turn (fig. 14-10) and the coordinates of the target predicted intercept point. These coordinates are needed to produce gyro angle, G; torpedo run, Hm6; and time of the torpedo run, T2-6.

At this point a few preliminary assumptions to simplify the study of the problem are in order. Ownship, a submarine, is in firing position and has determined an accurate range and bearing to the target. Both ownship and the target are on a straight course and are traveling at a constant speed. Ownship's deck plane is aligned with the horizontal plane. The target detection unit and the torpedo tubes are located at the system's reference point to eliminate ownship's parallax. Finally, standard ballistic conditions are present.

Coordinates of the Center of Turn

Each torpedo has a specific reach distance. The reach distance, R3, is the initial straight-line path taken by the torpedo when it leaves the tube. This distance, R3, allows the torpedo to become fully operational before it starts to maneuver. Moreover, the turning radius for each type of torpedo is also a constant. In other words, its track describes a definite arc for a given course change.

RECTANGULAR COORDINATES.—To establish the center of the turn (fig. 14-10), a line originating at the start of the turn is drawn perpendicular to the torpedo track. A second line originating at the completion of the turn is drawn perpendicular to the torpedo track. The point where the lines intersect is the center of the turn. The length of the lines is equal to Ym, the torpedo turning radius. The angle enclosed by the two lines is G, the torpedo gyro angle.

To calculate the center of the turn parallel to the line of sight (los), two more lines are drawn. One line is drawn perpendicular to the los and connects it to the point on the torpedo track where the turn is started. The second line is drawn perpendicular to the first line and terminates at the center of the turn. Two similar right triangles are formed. Notice that the angles B are complementary to the same angle and therefore are equal.

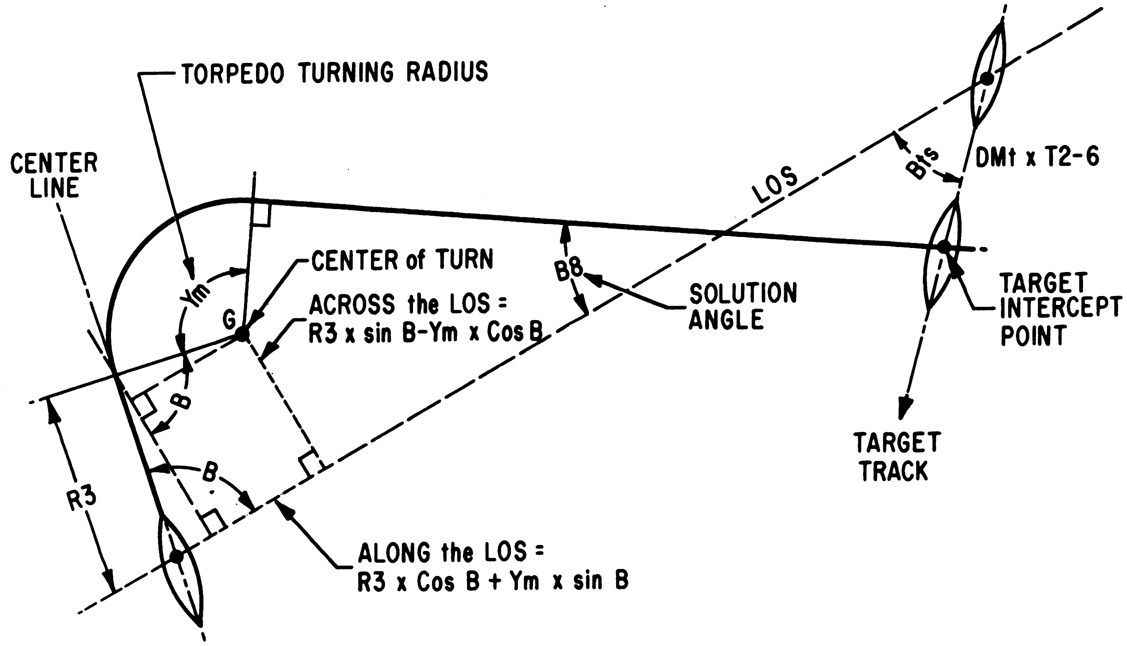

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Figure 14-10.—Geometry of torpedo prediction problem.

The first line that was drawn formed the right triangle whose hypotenuse is R3. The base of the triangle is equal to the product of R3 and the cosine of B. Parallax has been eliminated, but if it were to be considered the parallax base length would be added to the quantity R3.

The hypotenuse of the other right triangle is equal to the torpedo turning radius, Ym. The base of the triangle is equal to Ym multiplied by the sine of B. The sum of the two bases is equal to the rectangular coordinate of the center of the turn measured along the los with respect to ownship.

The rectangular coordinate of the center of the turn perpendicular to the los is equal to R3 sine B minus Ym cosine B. These quantities are calculated from the two right triangles that have been constructed.

Predicted Intercept Point

The rectangular coordinates of the predicted intercept point, which is located at the torpedo impact point, are computed from target speed, DMt; target angle, Bts; and time of the torpedo run, T2-6. Target lead distance (fig. 14-10), is equal to DMt multiplied by T2-6. The component of target motion along the los is equal to DMt times T2-6 cosine Bts. The component across the los is equal to DMt times T2-6 sine Bts. This is a straightforward method of resolving the predicted target linear movement during the torpedo run.

The linear components of the center of the turn, and of the predicted target motion that lie perpendicular to the los, are added algebraically to obtain the lead angle across the los. In surface fire control systems this would be the deflection angle; here, it is considered to be the initial gyro angle, G. Remember that the unknown quantity, T2-6, was used in the computation of G, and therefore G is initially inaccurate.

The linear components of the center of the turn and of the predicted target motion that lie parallel to the los are combined and then algebraically added to present range.

Now, rotate the los axis through the initial gyro angle to give the solution angle, B8. A line connecting the center of the turn with the predicted impact point is equal to the straight-track run distance of the torpedo, Hm4-6. The addition of the torpedo reach distance and the turn run distance to Hm4-6 gives the total torpedo run, Hm6. The torpedo reach distance is a constant. The torpedo turn run distance varies as a function of gyro angle, but otherwise it is a constant. Once Hm6 has been established, the time of the torpedo run can be calculated by using the following formula.

$$\text{T2-6} = \frac{\text{Hm6}}{\text{Uu}} \text{ (torpedo speed)}$$

The quantity T2-6 was used to compute the target lead distance, DMt x T2-6, which in turn was used to compute G and Hm6. Thus, a round-robin type of problem is developed, similar to the surface fire control problem, where T2 and R2 were computed. Accordingly, G and Hm6 are computed simultaneously in a regenerative network.

BALLISTIC CORRECTIONS AND ORDERS.—The ballistic corrections of emergence speed factor, jm(Hm), and depth change run difference, jv(Hm), modify the value of torpedo run, Hm6. These corrections change the value of T2-6 and all the predictions based on T2-6.

The latitude correction, j(Cm), is added to the gyro angle to compensate for the drift of the torpedo gyro caused by the difference between the torpedo proofing and firing latitudes.

An angular error proportional to the rate of change of ownship's course, DCo, is imparted to the torpedo. Ownship's motion is imparted to the torpedo; but since the torpedo tubes are fixed parallel to the ship's centerline, only the angular motion, DCo, need be considered in ballistics. The linear proportion of ownship's motion is part of the relative motion problem.

DCo acts on the torpedo from the time it is fired until the torpedo gyro is uncaged and takes control of its trajectory. Therefore, the correction is equal to the DCo multiplied by the time period involved. The time factor is a fixed value determined by the type of torpedo and the distance, R3. The correction is combined with gyro angle to compensate for the rate of course change error.

The point of aim can be changed by an order called shift along the target track, q(Hm). The offset, q(Hm), is added to the target lead distance to move the effective impact point either forward or aft of the MOT at the predicted intercept point. The quantity q(Hm) is similar to an arbitrary spot in the surface fire control systems.

Linear spread, sq(Hm), is used when torpedoes are fired in salvo. Its purpose is to stagger the points where the torpedoes cross the target track. Each torpedo in the salvo is assigned a number of units of spread either forward or aft of the MOT. Therefore, each torpedo has a slightly different point of aim and a salvo pattern is obtained. The amount of spread is determined by the number of units of spread selected for each torpedo.

TORPEDO ORDER TRANSMISSION.–The computed gyro angle and torpedo run depth are transmitted to the preset torpedo while it is in the tube. The orders are received continuously by data transmission systems and set by internal servosystems. Thus the orders are preset, and when the torpedo is fired its information is correct up to that instant.

PRESET PROGRAMMED TORPEDOES

The trajectory of a preset programmed torpedo is essentially that of a straight-running torpedo up to the point where the program is started. This point, called the enabling point, marks the beginning of the programmed phase of the run. The distance to the enabling point is called the enabling run. Enabling run, C(Hm), is related to torpedo run, Hm6, for straight-running torpedoes by enabling run offset, c(Hm) (fig. 14-11). Thus:

$$c(Hm) - Hm6 + c(Hm)j$$

The quantity c(Hm)j is inserted manually into the angle solver. Its value is determined by the geometry of the problem and the type of torpedo to be fired.

The straight-run torpedo problem is solved to put the torpedo in the general area of the target. At the enabling point, the torpedo shifts its control and the built-in program takes command of the control system. The torpedo then seeks its target in accordance with the preset program.

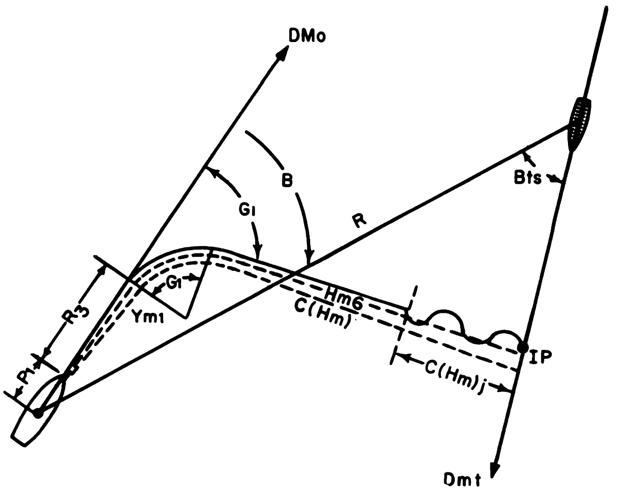

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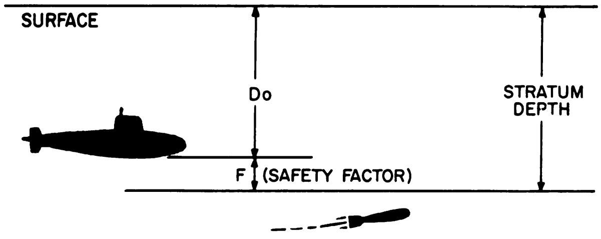
Figure 14-11.–Preset, torpedo-enabling run c (Hm) programmed.

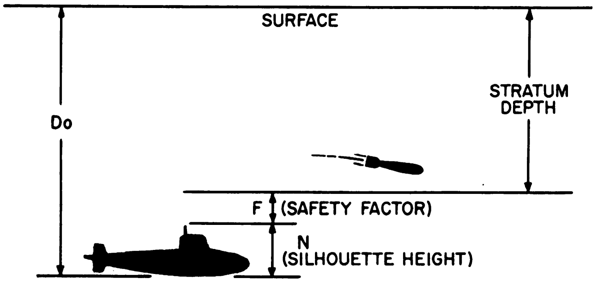
The preset program in figure 14-11 calls for the torpedo to search for the target by SNAKING; that is, turning left and right in order to "hear" the target. (Although they are not discussed here, there are many other types of search programs.) Notice that the torpedo is enabled before crossing the target's track, with the torpedo aimed at the intercept point. Thus, except for c(Hm)j, the computation for the programmed torpedo is the same as for the straight-run shot.

Stratum Limit

Torpedoes which can be ordered to run at a certain depth and then search for a target by acoustical means may be dangerous to ownship, should ownship be at or near the search depth. Torpedoes are instructed to search above or below a certain depth, called stratum depth. If ownship is in the depth range in which the torpedo is searching, then the computer gives a warning to this effect. Refer to figure 14-12. Do is the depth of the keel of ownship. A torpedo which is searching below a certain depth is referred to as a torpedo running below stratum. In this case, a safety factor is added to ownship



TORPEDO RUNNING BELOW STRATUM



TORPEDO RUNNING ABOVE STRATUM

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Figure 14-12.—Stratum relationships.

depth and any depth below this is considered safe. A torpedo which is searching above stratum depth is referred to as a torpedo running above stratum. In this case, the height of ownship (plus a safety factor) is subtracted from ownship depth to determine the safe level of search.

It can be seen that the torpedo's search pattern is limited by stratum depth. The stratum establishes the upper or lower depth at which the torpedo searches. The depths between which the torpedo will search is called the stratum limit.

WIRE-GUIDED TORPEDOS

Wire-guided torpedoes can be controlled after firing by commands sent over a communication wire, which connects the running torpedo with the submarine. The wire-guided torpedo run starts in the same manner as a preset torpedo run. The torpedo is launched, completes its reach run, and then turns through a preset gyro angle. At the completion of the turn, corrections can be made to the trajectory through the wire.

There are two modes of operations or methods used to guide the torpedo to the target, the bearing rider mode and the corrected intercept mode. The bearing rider mode is used when target data—either range, course, or speed—is not considered reliable. In this mode, the torpedo "rides" the bearing line. A collision course is maintained between the torpedo and the present position of the target. Since the bearing line is constantly changing, continuous corrections are usually needed. When reliable target data is available, the corrected intercept mode of operation is used. In this mode, the torpedo is steered toward the predicted impact point.

Bearing Rider Mode

To maintain the torpedo course coincident with the target bearing line, it is readily apparent that the position of the torpedo must be known at all times. Torpedo position with respect to ownship is computed by dead reckoning. This is accomplished by algebraically adding the components of ship motion to the components of torpedo motion. In effect, a relative motion problem is being solved. The factors in the problem are the initial position of ownship and the torpedo at the start of the problem, plus the course and speed of ownship and the torpedo. Since all these factors are known, the solution is accurate.

Torpedo bearing is compared continuously with target bearing. When the two are in agreement and torpedo course is along the los, the torpedo track is correct. If there is a difference between the two bearings, the torpedo course is adjusted by wire-guide commands to bring them back into alignment.

Corrected Intercept Mode

In the corrected intercept mode of operation, the torpedo trajectory resembles that of a preset torpedo. As a matter of fact, if no target maneuvers are encountered and the initial solution was correct, the two problems are identical. Therefore, the solution to the straight-running torpedo problem is the basis of the corrected intercept solution.

After the torpedo is launched, the problem is continuously recalculated; however, the torpedo position is now the reference instead of ownship's position. Torpedo position is computed by dead reckoning, and is a known factor. Since the range and bearing to both the torpedo and the target are known with respect to ownship, the torpedo's position can be related to the target's position. When the torpedo-to-target range and bearing are determined, a new and more accurate impact point is computed. Corrective signals are then sent to the torpedo to alter its course to the new predicted target intercept point.

Wire-guide Signals

In addition to the steering orders, other types of command signals may be transmitted over the communication wire. Signals such as orders to change the distance of the enabling run, to change the torpedo's mode of operation, or to detonate the torpedo warhead may be sent from the submarine to the torpedo. The torpedo, in turn, may send back to the submarine signals indicating its status: ready to accept steering orders; have started searching or homing operation; have contacted target; and so on.

CHAPTER 15

UNDERWATER FIRE CONTROL SYSTEMS

As mentioned in chapter 11, the term "fire control" means the directing of various weapons so that they will hit a desired target. One way of accomplishing this is with an underwater weapon control system. An underwater weapon system is comprised of a group of instruments working together to direct a weapon to a desired target.

This chapter describes the functional sections of an entire weapon system aboard a submarine with emphasis on the underwater fire control system (UFCS). An underwater fire control system is a major subsystem of the weapon system. The description is of a general nature and applies to all underwater systems. Keep in mind that there are variations between different modifications (Mods) of a system (analog or digital, physical location of devices, types of weapons controlled, etc.), but for the most part, the functional descriptions of underwater systems do not vary to any great extent.

Physical descriptions of the Mk 113 and Mk 117 UFCSs are also provided. It is, however, impractical to cover all the mods of these systems; therefore, a representative of each system has been selected. Before getting into the physical features, however, let's consider the functional aspects of the overall underwater weapon system.

WEAPON SYSTEM

The weapon system is essential in performing the primary mission of the submarine—to seek out and destroy an enemy target. The weapon system should not be looked upon as a single item. Instead, it should be considered as a composite of the ship, the crew, and the shipboard equipment operating together to perform the primary mission. Shipboard equipment systems included in the weapon system are target acquisition devices, ownship's sensors, data display, computer complex, weapon order subsystem, and weapons. When these individual subsystems are joined to form the weapon system, the overall system can be divided into four functional sections: data acquisition, data processing and analysis (including display), weapon order, and weapons (fig. 15-1).

DATA ACQUISITION

The data acquisition section (fig. 15-2) consists of sensors which supply target and ownship data to the data processing and analysis section. It employs eight primary data sources: sonar, radar, periscope, Ship Inertial Navigation System (SINS), gyrocompass, electromagnetic

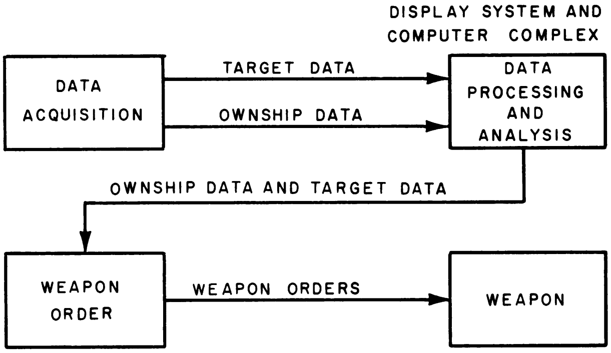

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Figure 15-1.—Weapon system functional sections.

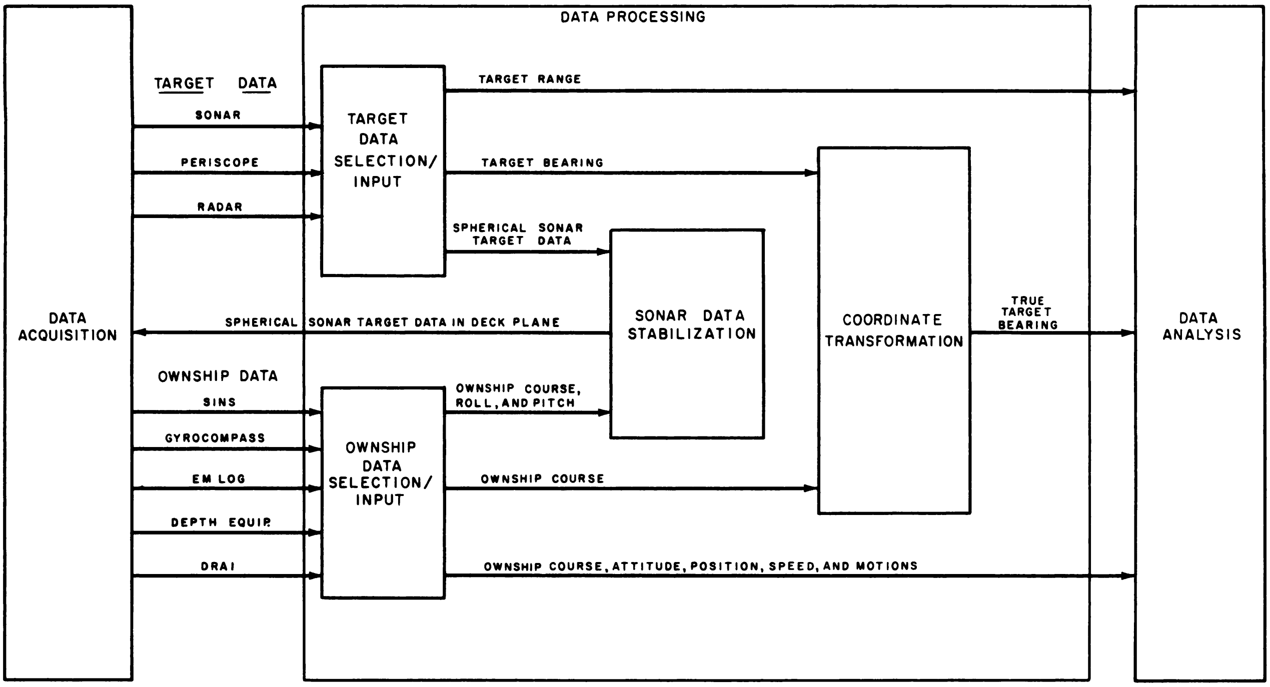
DATA ACQUISITION
TARGET DATA
SONAR
PERISCOPE
RADAR
SPHERICAL SONAR TARGET DATA IN DECK PLANE
OWNSHIP DATA
SINS
GYROCOMPASS
EM LOG
DEPTH EQUIP
DRAI
DATA PROCESSING
TARGET DATA SELECTION/ INPUT
TARGET RANGE
TARGET BEARING
SPHERICAL SONAR TARGET DATA
SONAR DATA STABILIZATION
COORDINATE TRANSFORMATION
TRUE TARGET BEARING
OWNSHIP DATA SELECTION/ INPUT
OWNSHIP COURSE, ROLL, AND PITCH
OWNSHIP COURSE
OWNSHIP COURSE, ATTITUDE, POSITION, SPEED, AND MOTIONS
DATA ANALYSIS

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Figure 15-2.—Data acquisition/data processing and analysis functional sections.

(EM) log, master depth detector, and dead-reckoning analyzer indicator (DRAI).

Sonar

As mentioned in chapter 14, sonar is an acoustic system that operates in either an active (pinging) or passive (listening) mode. The target data available depends upon the mode of operation.

Active mode sonar supplies the apparent relative bearing, apparent depression angle, and apparent range. Apparent relative bearing is the bearing of the line of sound to the apparent position of the target relative to ownship centerline (OSCL). The apparent depression angle is the angle between ownship's deck plane and the line of sound to the apparent position of the target. Apparent range is the distance from ownship to the apparent position of the target. The sonar apparent target position may differ from the actual target position because of variances in sound velocity and the bending of sound waves. The amount of bend depends upon variables such as water temperature, salinity, and depth. Therefore, sonar data is apparent data.

Passive mode sonar supplies the apparent relative bearing and the depression angle. Range data is not available in this mode and must be computed.

Radar and Periscope

Radar is used to locate surface targets and provides range and target bearing information. The periscope is used to provide relative bearing data on a surface target.

Ship Inertial Navigation System (SINS)

The (SINS) is a source of ownship data and consists of a stable platform and a digital computer. The stable platform is inertially referenced and contains devices to measure ship velocities and angular quantities. The digital computer uses the velocity and angular quantity outputs of the stable platform to continuously update initial ownship's position. Data outputs from the SINS that are used by the weapon system are ownship's latitude, course, roll, pitch, north velocity, east velocity, and velocity along OSCL.

Gyrocompass

The gyrocompass is an inertially referenced stable platform containing devices to measure ownship's roll, pitch, and heading. This information is provided to the data processing section of the weapon system.

Electromagnetic (EM) Log

The EM log measures the speed of ownship relative to the water and provides an output of ownship's speed.

Depth Equipment

The depth equipment consists of a master depth detector that uses water pressure to measure the distance from ownship's keel to the water surface and provides an output of ownship's depth.

Dead-Reckoning Analyzer Indicator (DRAI)

The DRAI uses ownship's course from the gyrocompass or SINS and ownship's speed from the EM log or SINS to generate ownship's north position, ownship's east position, and the rate of change for each.

DATA PROCESSING AND ANALYSIS

The data processing and analysis section (fig. 15-2) includes target and ownship data selection, sonar data stabilization, coordinate transformation circuits, and target motion analysis. These functions are necessary to prepare the data for use in the weapon order section

Target Data Selection Circuits

Target data selection circuits selects one of the three sources of target data (sonar, radar, or periscope). Selected sonar target data is the output of one of the sonar systems (active or passive). Outputs of the selected sonar system are routed to the data analysis section. Radar target data is the output of ownship's radar system and is routed to the data analysis section. Selected periscope target data is the output received from the periscope.

Ownship's Data Selection Circuits

Ownship's data selection circuits choose the source for each type of ownship's data and transmit the data to the appropriate circuits. Ownship's course, roll, and pitch are obtained from either the SINS or the gyrocompass, and then are routed to the sonar stabilization circuits. Ownship's course is also routed to the coordinate transformation circuits. Ownship's speed, available from either the SINS or the EM log, is transferred to the data analysis section. Ownship's latitude, available from the SINS, is routed to the data analysis section. Ownship's north and east positions and velocities are available or are developed from data supplied by either the SINS or the DRAI, and are routed to the data analysis section. Ownship's depth, available from the depth equipment, is routed to the data analysis section.

Coordinate Transformation Circuits

Coordinate transformation circuits perform two functions: (1) the conversion of data measured at different points on ownship to data referenced to a common point and (2) the conversion of relative bearing to true bearing. Reference point conversion is performed so that all data used by the data analysis section is referenced to a common point. (As mentioned in chapter 14, a submarine's reference point is normally one of the periscopes.)

Ownship data is measured from a point defined as the intersection of a deck and a normal plane through the periscope centerline that is perpendicular to OSCL. This point is referred to as the master origin. Sonar data is measured from a point on the OSCL coinciding with a plane that is perpendicular to the center of the hydrophone arrays (forward of the master origin).

All input data is measured from the master origin. Therefore, before mathematical analysis of ownship and target data can be performed, both sets of data must be referenced to the master origin. Consequently, sonar data is translated, as required, from the sonar reference points to the master origin. This translation, possible because the sonar reference point has a known relationship to the master origin, is performed by the coordinate transformation circuits.

The data analysis section also requires that all data be referenced to the north and east coordinates (true data). Target bearing data from the data acquisition section is relative and is, therefore, rotated from ownship's reference to the north-east reference.

Data Analysis Section

Data analysis is performed by the computer complex which uses target and ownship data to compute target range, course, and speed. This analysis is termed target motion analysis. Inputs used in the mathematical process of target motion analysis are true bearing, ownship's course and speed, and, if available, apparent target range and range rate from the data processing section. Because the sonar system normally is operated in the passive mode (to reduce the probability of ownship's detection), range and range rate data may not be available. Therefore, the computer complex is capable of computing the necessary target parameters with only target bearing and ownship's motion inputs. Processing of this data is referred to as a bearings-only solution. The target course, speed, bearing, and range outputs of the target motion analysis are updated continuously with available target data inputs and then routed to the target position keeping computation section within the weapon order section.

WEAPON ORDER SECTION

The weapon order section (fig. 15-3) determines the future position of the target, computes the required weapon orders, transmits the weapon orders to the weapon, and maintains surveillance of the target and weapon position subsequent to the firing order. To do this, the weapon order section functions include target position keeping, weapon path computations, torpedo position keeping, and torpedo error computations.

It was stated in chapter 14 that the underwater fire control problem could be divided into two major functional sections: the relative motion section and the ballistic section. It was further stated that the relative motion problem was solved in what is referred to as the position keeper section of the UFCS and the ballistic problem was solved in the angle solver section.

It is in the weapon order functional section of a weapon system that these two functional sections of the UFCS—relative motion and ballistic—are found.

Target Position Keeping

Target position keeping (fig. 15-3) analyzes target motion to determine the rate of change of target position. This rate of change is used to advance target position with respect to real time. Data from target motion analysis occurs at discrete intervals, but weapon path computations require continuous target position. Target position keeping supplies this data. To "position keep" a target, the speed, course, range, and bearing of the target are used to compute incremental changes in target range and bearing. These increments update (in real time) the target position with respect to ownship, and thereby maintain the target position between data inputs. When data from the target motion analysis occurs, the data is compared with the target position computed by the position keeping process. If the two sets of data do not agree, position keeping data is updated to reflect the latest target motion analysis data. Because target motion is computed with respect to ownship, ownship's motions also affect target position. Therefore, ownship's course and speed are included in target position keeping computations. If target motion analysis data is not available, target position keeping can be performed using target data obtained directly from the data processing section or by using manually entered data.

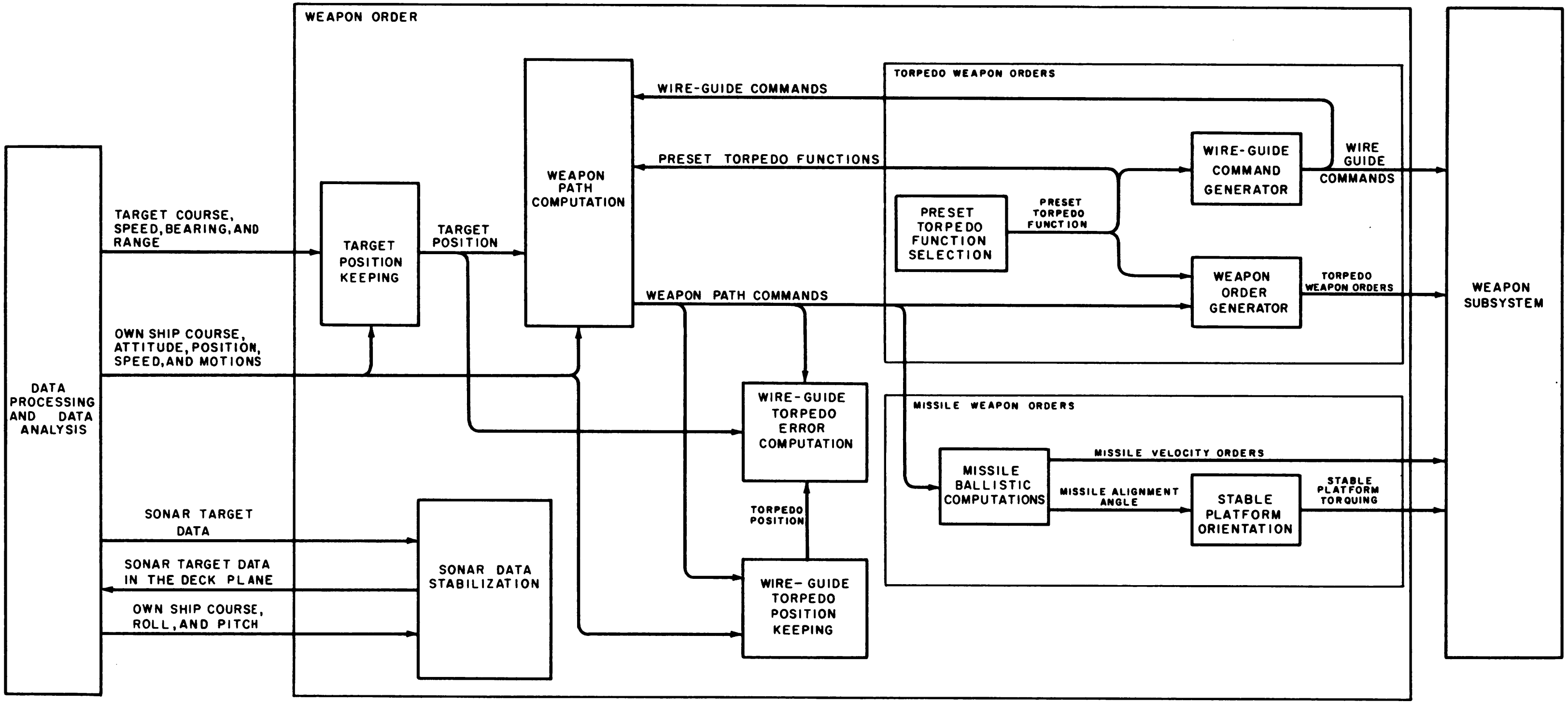

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Figure 15-3.—Weapon order functional section.

Weapon Path Computations

Weapon path computations result in weapon path commands that, after conversion to weapon orders, direct the weapon to follow a course that will intercept the target. To compute weapon path commands, weapon path computation circuits store ballistic constants for all weapons compatible with that UFCS. When a weapon is selected, weapon path computation circuits use the proper ballistic constants, ownship data, and target position to generate these commands. For some weapons, certain parameters (such as run depth) are not automatic functions but are manually preset into the weapon at the weapon order section. Manually preset functions which affect the weapon path are routed from the weapon order section to the weapon path computations. Computation of a path that intercepts the target is made by advancing the target along its present course to a point determined by the time necessary for the weapon to travel from ownship to the predicted target position. A path that intersects this point, and the weapon travel time along this path, are computed. The computed target intercept point then is advanced or retarded by an amount proportional to the difference between the two travel times. This approximation process continues until the weapon path and target course intersect at a target position advanced along the present target course computed by the travel time of the weapon. Weapon path commands resulting from these computations are routed to the wire-guided torpedo position keeping circuits, wire-guided torpedo error computation circuit, and the weapon order section.

Wire-Guided Torpedo Position Keeping

The wire-guided torpedo position keeping process permits comparison of the actual and computed target path and computes the error in the torpedo path resulting from target maneuvers. When the selected wire-guided torpedo is fired, the weapon path computations are locked, and changes in target position do not change initial path commands. Torpedo position keeping constantly marks the position of the torpedo along this path. To accomplish this, the speed of the torpedo and the elapsed time from fire are used to compute the distance the torpedo has traveled along the commanded path. Wire-guided commands generated by the weapon order section (after firing) correct the locked computations by the same amount the torpedo path is changed.

Wire-Guided Torpedo Error Computations

Wire-guided torpedo error computations determine the error in the torpedo path caused by target maneuvers. To compute torpedo errors, new target position and torpedo position data are used to compute a new intercept point. The differences between this point and the original intercept point are the errors in the previous torpedo path. These errors are displayed so the operator is able to determine what torpedo path changes are to be made and when to make them.

Missile Weapon Orders

Another weapon that can be launched by a submarine and controlled by the weapon order section is a missile called the SUBROC. Basically, this missile is launched from the submarine, surfaces, flies a ballistic trajectory, reenters the water over a target, and delivers a depth bomb to the target (fig. 15-4).

Because the SUBROC missile and torpedo guidance system differ, the weapon order section trajectory commands must be converted into guidance quantities and then into missile weapon orders for insertion into a SUBROC missile.

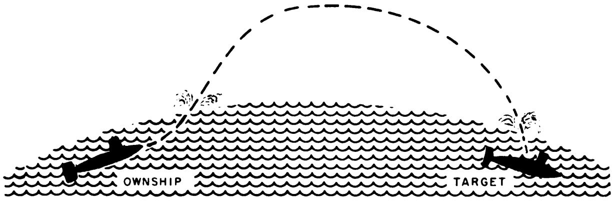

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Figure 15-4.—SUBROC trajectory.

WEAPON SECTION

The weapon section (fig. 15-5) is that functional portion of the weapon system which delivers the warhead to the target. It has the capability of preparing and firing four major types of weapons: preset torpedoes, wire-guided torpedoes, SUBROC missiles, and HARPOON missiles.

Preset Torpedo

A preset torpedo is not controlled by the weapon system after firing. Commands that control the torpedo path to the target intercept point are set into the weapon prior to firing. A typical preset torpedo consists of a control subsystem, a propulsion subsystem, a warhead, and (in certain torpedos) a homing subsystem.

Wire-Guided Torpedo

A wire-guided torpedo is similar to a preset torpedo, except that, after firing, the wire-guided torpedo can be controlled by wire-guided commands. The UFCS is capable of computing paths and generating commands for a multispeed, deepdiving, long-range torpedo with an acoustic homing subsystem for use against surfaced or submerged targets.

SUBROC Missile

The SUBROC missile is an inertially guided ballistic missile that delivers a depth bomb to a water reentry point above the target. Functionally, this weapon consists of guidance, control, and propulsion subsystems, and a warhead.

HARPOON Missile

The HARPOON missile system is a subsystem of the submarine's primary weapon system, just as it is in surface weapon systems. It is not fully integrated with the primary system in the strict sense of the word. In many respects, it can be looked upon as an add on to an existing system.

On submarines, the HARPOON system receives target information from the weapon order section. The information is used to determine control functions, which are inserted by an operator. In addition, the information is used to generate orders for the missile.

UFCS MK 113

The UFCS Mk 113 can control the SUBROC missile and both wire-guided and preset torpedoes. The major units that make up the UFCS are located in the attack center and the torpedo room of the submarine (fig. 15-6). Each of the units performs a specific portion of the total UFCS function. The major units are as follows:

- Attack console
- Weapon monitor panel
- Weapon simulator

The attack center switchboard, torpedo room switchboard, amplifier, indicator panel, and switchbox are also described in this section, although not integral parts of the UFCS. They are, however, necessary for the UFCS-to-weapon interface.

ATTACK CONSOLE

The attack console (figs. 15-6 and 15-7) is located on the starboard side of the attack center and is the primary control center for the UFCS. It is composed of the attack control console, the attack director, the analyzer console, the signal data converter, the digital interconnecting box, the torpedo control console, and the tone signal generator.

Attack Control Console

The attack control console (fig. 15-7) consists of the plotter, firing panel, and ownship sections. It monitors and displays the tactical situation and also monitors and controls the weapon launching sequence.

THE PLOTTER SECTION.–The plotter section provides a geographic display of

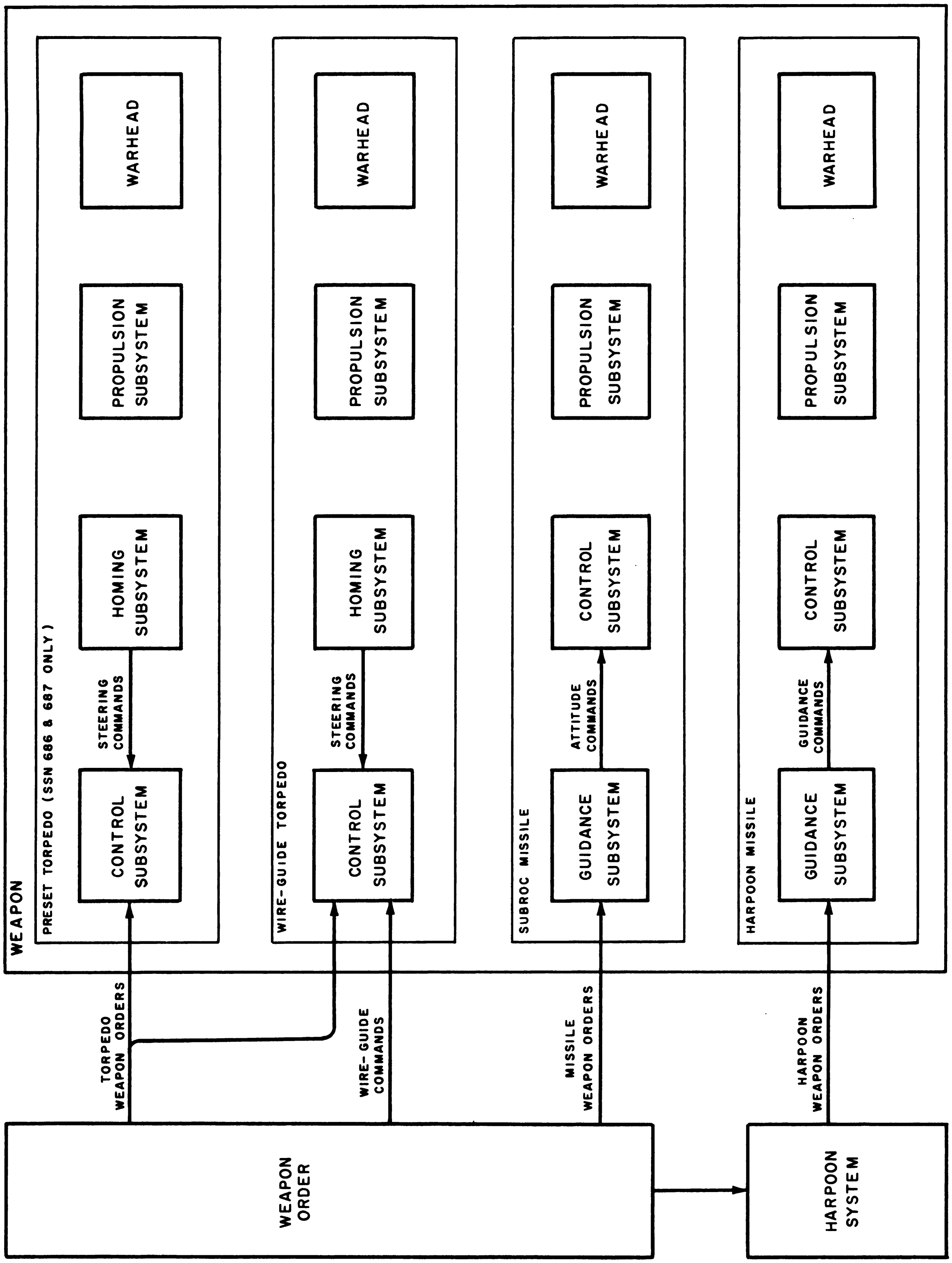

Figure 15-5.—Weapon functional section.

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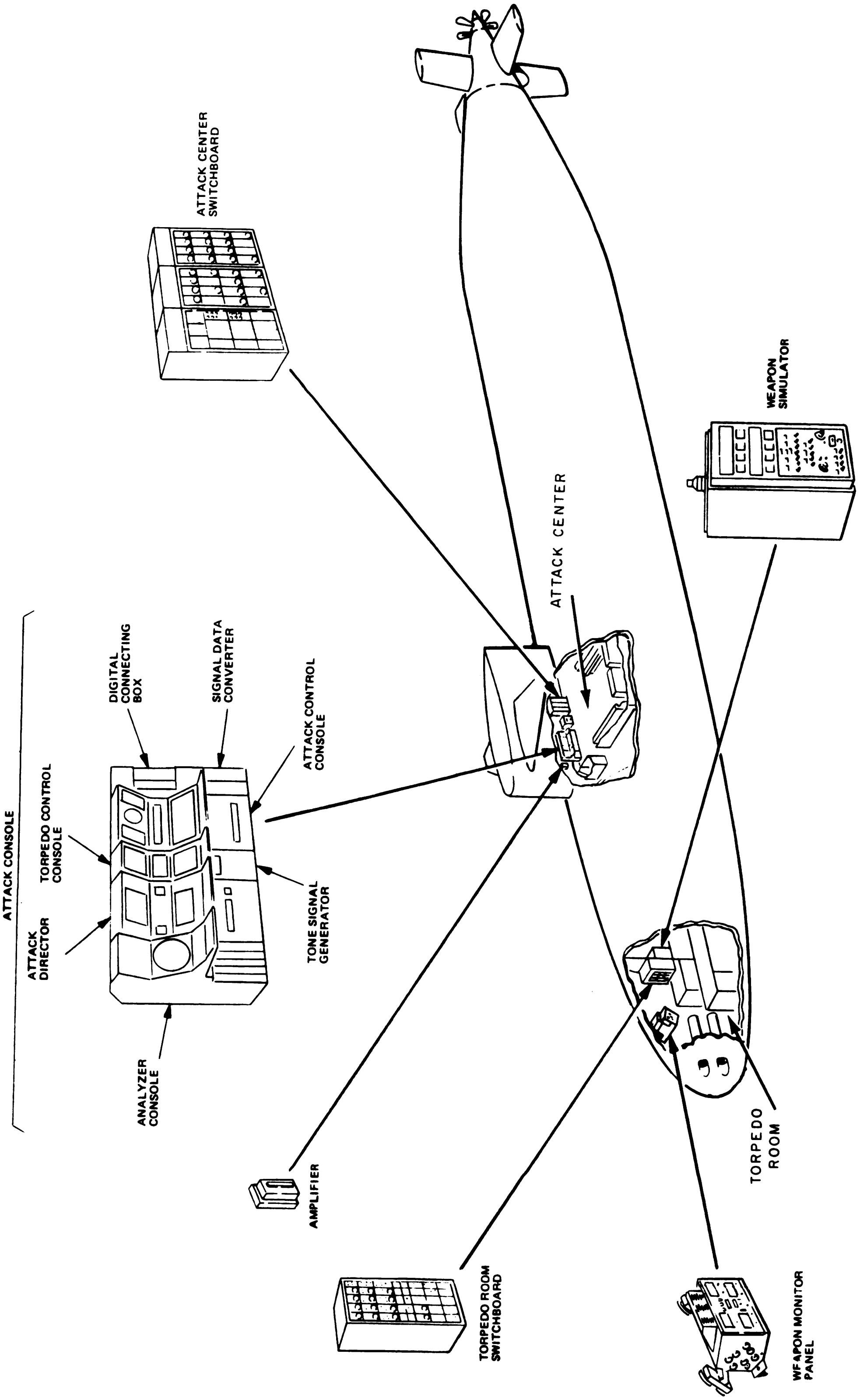

Figure 15-6.—UFCS Mk 113.

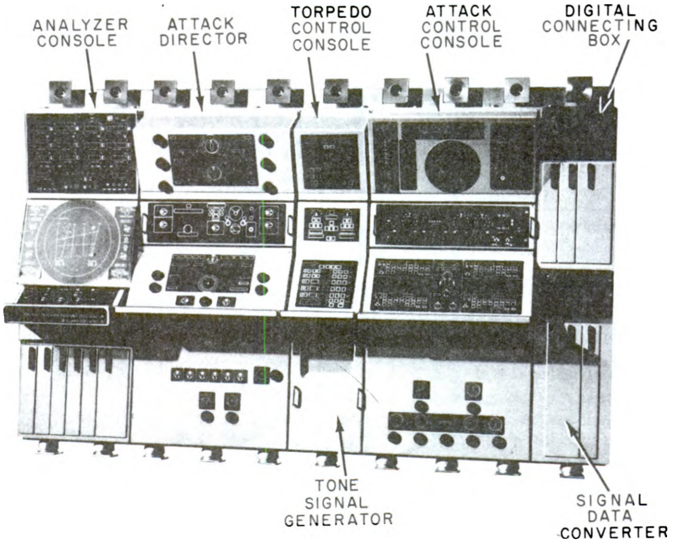

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Figure 15-7.—Attack console.

ownship, target, and wireguided torpedo positions. To provide this display, the plotter section receives target position from the analyzer console, wire-guided torpedo position from the attack director, and ownship data from the ownship section. The torpedo tube firing sequence and certain preset functions for torpedos are selected at the plotter section.

THE FIRING PANEL SECTION.—The firing panel section displays the status of the weapon and the torpedo tube, and controls the weapon launching sequence. Weapon and torpedo tube status displays on this section are controlled by signals received from the weapon monitor panel and the attack director. Switches control assignment of the attack director to a torpedo tube. Setting of the angular or linear spread patterns firing of the weapon from the attack center is controlled by this section.

THE OWNSHIP SECTION.—The ownship section receives and displays analog values of ownship's course, speed, roll, and pitch. This section also performs relative-to-true and true-to-relative bearing conversions, and computes ownship's north and east motions.

Attack Director

The attack director (fig. 15-7) is a target position keeper, torpedo order computer, and wire-guided torpedo position keeper. The attack director computes current target position; solves the underwater fire control problem; selects the source of target range and bearing data; selects the position keeper mode of operation; and serves as a remote control station for wire-guided torpedoes after launch. The attack director consists of the position keeper display, position keeper control, angle solver, and ballistic computer sections.

THE POSITION KEEPER DISPLAY SECTION.—The position keeper display section receives and displays ownship and target data. This section also contains a portion of the circuitry used in attack director computations.

THE POSITION KEEPER CONTROL SECTION.—The position keeper control section switches select the source of target range and bearing data applied to the attack director. This section also controls operation of range and bearing position keeping circuits. Torpedo ballistic constants are automatically or manually selected at this section. A meter and associated controls monitor the continuity of the guide wire attached to wire-guided torpedoes.

THE ANGLE SOLVER SECTION.–The angle solver section displays internally computed torpedo quantities; generates error signals for setting torpedo synchronous functions; indicates limit functions for each type of weapon; and controls transmission of commands to wire-guided torpedoes after launch. This section also contains a portion of the circuitry involved in torpedo order and wire-guided torpedo position keeping computations.

THE BALLISTIC COMPUTER SECTION.– In the ballistic computer section, the errors between computed and observed target range and bearing are developed and the speed correction factor for each type of torpedo is controlled. Match or unmatched signals for gyro angle, enabling run, and running depth functions are developed in this section and transmitted to the weapon monitor panel. The computed values of weapon time to burst and the received values of ownship's latitude are displayed in this section. Manual controls are provided for both of these functions.

Analyzer Console

The analyzer console (fig. 15-7) provides man-machine interface between a target motion analysis operator and a digital ballistic computer. It contains a cathode-ray tube (crt), buffer memory, vector generator, symbol generator, logic, and readouts required for displaying target motion analysis data. Target range and bearing source select switches are provided for selecting sensor data. Encoders and pushbuttons are used to enter data, constrain solution parameters, and modify display and readout information. The crt and numerical readouts indicate the status of computer input and output information. The controls, encoders, keyboard, and indicators allow the motion analysis console operator to modify and control all target motion analysis processes.

Signal Data Converter

The function of the signal data converter (fig. 15-7) is to provide analog-to-digital and digital-to-analog conversion. Analog inputs are received by the signal data converter in the form of high- and low-speed synchro data, and are converted to digital words. Also, digital words are received from the digital computer and converted to high- and low-speed synchro data.

The signal data converter provides the interface between the analog inputs of target range and bearing from ownship's sensors and the digital computer. Ownship's course and speed are also converted from synchro to digital form by the signal data converter. As output quantities, the signal data converter converts computed target motion and analysis solutions from digital to analog form. These output quantities are computed range, course, speed, and bearing. These output quantities are sent to the attack director.

Digital Interconnecting Box

The function of the digital interconnecting box is to act as an interface for the transfer of digital information between as many as six users. At present, there are only three users–the digital computer, the analyzer console, and the signal data converter.

The digital connecting box contains six input channels for reception of digital data from six possible independent data sources. All digital data received from any source is stored by the digital interconnecting box for transmission to a maximum of six possible data users. Transmission to the data users is over a single set of lines, called the party line, using a broadcast technique.

Torpedo Control Console

The torpedo control console is used only with the wire-guided torpedo. Controls on the torpedo control console allow the operator to accomplish the following:

- Assign the console to a torpedo tube

- Select one of four groups of preset tactics

- Individually preset the trajectory mode, anti-self homing (ASH), pre-enable speed, search speed, search mode, acoustic mode, Doppler enable, ping interval, pitch angle, search depth, floor setting, ceiling setting or operating depth setting, and target mode parameters

- Command readback of the functions set into the torpedo

- Select one of the two function memories contained in the console and the tone signal generator

- Select the most desirable laminar distance for existing conditions

- Command changes after torpedo launch to search depth, pitch angle, pre-enable speed, search speed, acoustic mode, search mode, Doppler enable, and keylock parameters

- Check torpedo acceptance of wire-guided commands prior to launch

- Monitor continuity of the torpedo guide wire after launch

Console indicators display selected preset and commandable functions, gyro angle, remaining run-to-enable, percentage of fuel remaining, and selected laminar distance.

During preset operations (prior to launch), all torpedo functions except gyro angle are set into the torpedo by the torpedo control console. Gyro angle is set into the torpedo by the attack director and monitored by the torpedo control console. Run-to-enable c(Hm) is received from the attack director by the torpedo control console and set into the torpedo. Other preset functions are set into the torpedo when selected by the operator. As preset functions other than gyro angle and run-to-enable are set into the torpedo, the selected function settings are stored in one of the two memories contained in the torpedo control console and the tone signal generator. The operator selects the memory used to store the preset functions. The two memories permit each torpedo control console to preset and wire-guide command two torpedoes. The two torpedoes, controlled by one torpedo control console, are preset separately and can be wire-guide commanded individually or simultaneously. The torpedo control console also provides a readback capability that permits the operator to command a display of the preset functions set into the torpedo. The torpedo control console routes a pseudo-launch point correction and laminar distance to the attack director for inclusion in the order computations for wire-guided torpedoes.

During postlaunch operations, wire-guided commands other than course and run-to-enable are selected at the torpedo control console. Course and run-to-enable changes are selected at the attack director, and appropriate signals are routed to the torpedo control console. When a wire-guided command is selected, the torpedo control console routes a tone select signal to the tone signal generator, causing the appropriate tone command to be transmitted to the torpedo via the guidance wire.

Tone Signal Generator

Tones of different frequencies that are routed to the torpedo as wire-guide commands are produced by the tone signal generator. Each frequency represents a different command. The tones are generated under control of d.c. signals furnished by the torpedo control console. The tone signal generator also contains dual memories that store two sets of selected preset functions. Selection of one of the memories at the torpedo control console causes the stored set of preset functions to be set into the torpedo automatically.

WEAPON MONITOR PANEL

A display of weapon and torpedo tube status and operator control of certain functions are provided by the weapon monitor panel (figs. 15-6 and 15-8). Controls and indicators mounted on this panel are divided into six groups: Four torpedo type status groups, a firing order group, and a gyro angle—enabling run—running depth group. Each tube status

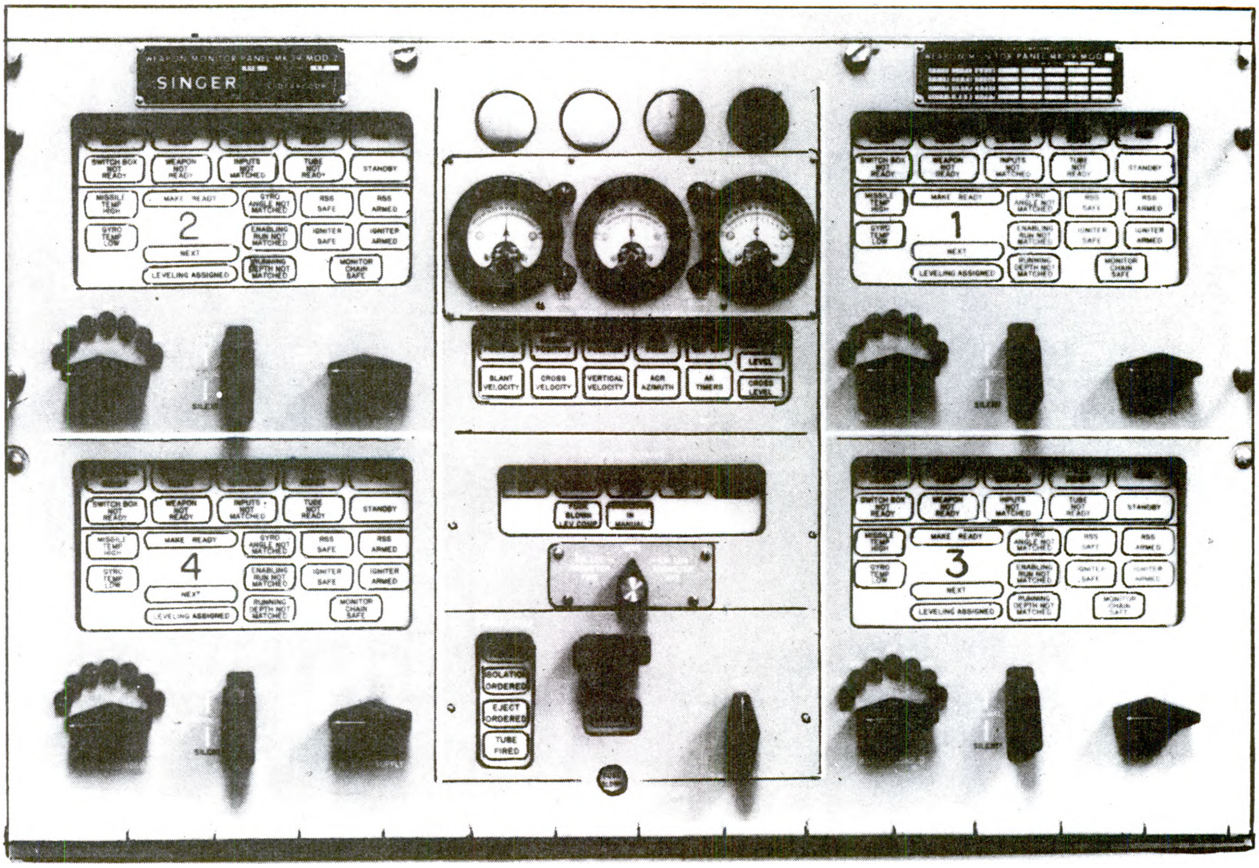

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Figure 15-8.—Weapon monitor panel.

group contains a WEAPON LOADED switch, a LOCAL FIRE—NORMAL—SILENT switch, a WEAPON SUPPLY switch, and a tube status indicator group. The WEAPON LOADED switch is positioned to agree with the type of weapon loaded in the torpedo tube. Positioning this switch automatically causes the WEAPON SELECTED display on the attack director to roll to a selected weapon when ballistics are set at the attack control console; thus, the proper ballistic constants for the loaded weapon are automatically selected. Positioning the switch to either LOCAL FIRE (torpedo room) or SILENT (swimout) causes immediate weapon launching. When the switch is in the NORMAL position, weapon firing is controlled at the attack control console. The WEAPON SUPPLY switch selects the status of equipment associated with weapon firing and the matched or unmatched condition of the appropriate weapon inputs.

The FIRING ORDER group displays the tube firing order selected at the attack control console.

The GYRO ANGLE—ENABLING RUN—RUNNING DEPTH group displays the magnitude of the errors in G, c(Hm), and Hvm stored in the torpedo. These errors are reduced to zero prior to launch.

WEAPON SIMULATOR

The weapon simulator (fig. 15-6) allows operator training and UFCS testing by simulating the wire-guided torpedo. The weapon simulator is connected to the output of the UFCS during testing and training modes and simulates the loads and functions of the wire-guided torpedo. Each UFCS output of the simulator is displayed, and controls mounted on the simulator permit insertion of simulated malfunctions.

ATTACK CENTER SWITCHBOARD

The attack center switchboard (fig. 15-6) provides interfacing between the UFCS, the auxiliary equipment, and the weapon. Switches mounted on this switchboard determine which equipment is connected to the UFCS, control the routing of inputs and certain UFCS-generated data, and control the application of power to UFCS equipment.

TORPEDO ROOM SWITCHBOARD

The torpedo room switchboard (fig. 15-6) provides interfacing between the UFCS and the weapon. Switches mounted on this switchboard are positioned to connect equipment necessary for weapon preparation and to launch the weapon.

AMPLIFIER

The amplifier, located in the attack center (fig. 15-6), converts the torpedo error signal outputs of the attack director into servomotor drive signals which are routed to the torpedo to null the errors.

UFCS MK 117

The UFCS Mk 117 can control the SUBROC missile, both the preset and the wire-guided torpedoes and the HARPOON missile. This system features attack center equipment that is mostly digitalized, replacing the older analog equipment. This provides the UFCS Mk 117 with high-speed, multipurpose operational consoles, while reducing the overall system size.

The entire weapon system is shown in figure 15-9 so that you may visualize the occurrence of events from ownship's sensors to the weapons. Only the major units of the UFCS Mk 117 are discussed in this section. The major units in the attack center are the:

- Weapon control console
- Attack control console
- Control panel
- Weapon data converter
- Amplifier
- Attack center switchboard
- Computer equipment

The major units in the torpedo room are the:

- Leveling computer
- Torpedo room switchboard
- Weapon monitor panel
- Missile heater controller
- Switch box

WEAPON CONTROL CONSOLE

The weapon control console (fig. 15-9) is the primary operator interface between the computer and fire control equipment. It interfaces with the computer through digital input/output channels for data control and display and through power distribution panels for power.

Figure 15-10 shows the weapon control console control panel. Console controls (intensity, focus, position, etc.) are on the vertical panels immediately to the right of the cathode-ray tube (crt). System controls, located on the horizontal panel, are as follows:

- Twenty-one pushbuttons are fixed-function switches for important or frequently used functions.

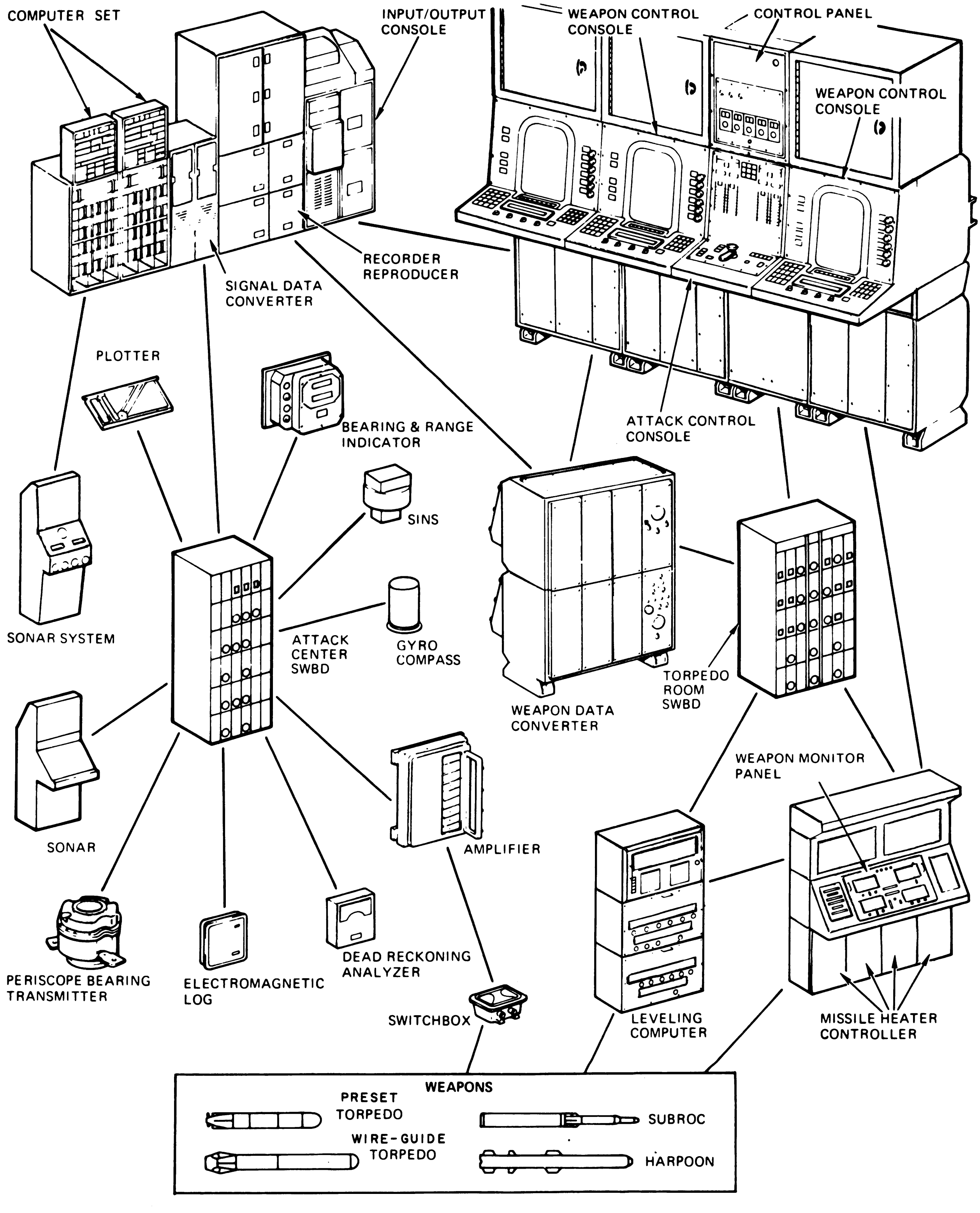

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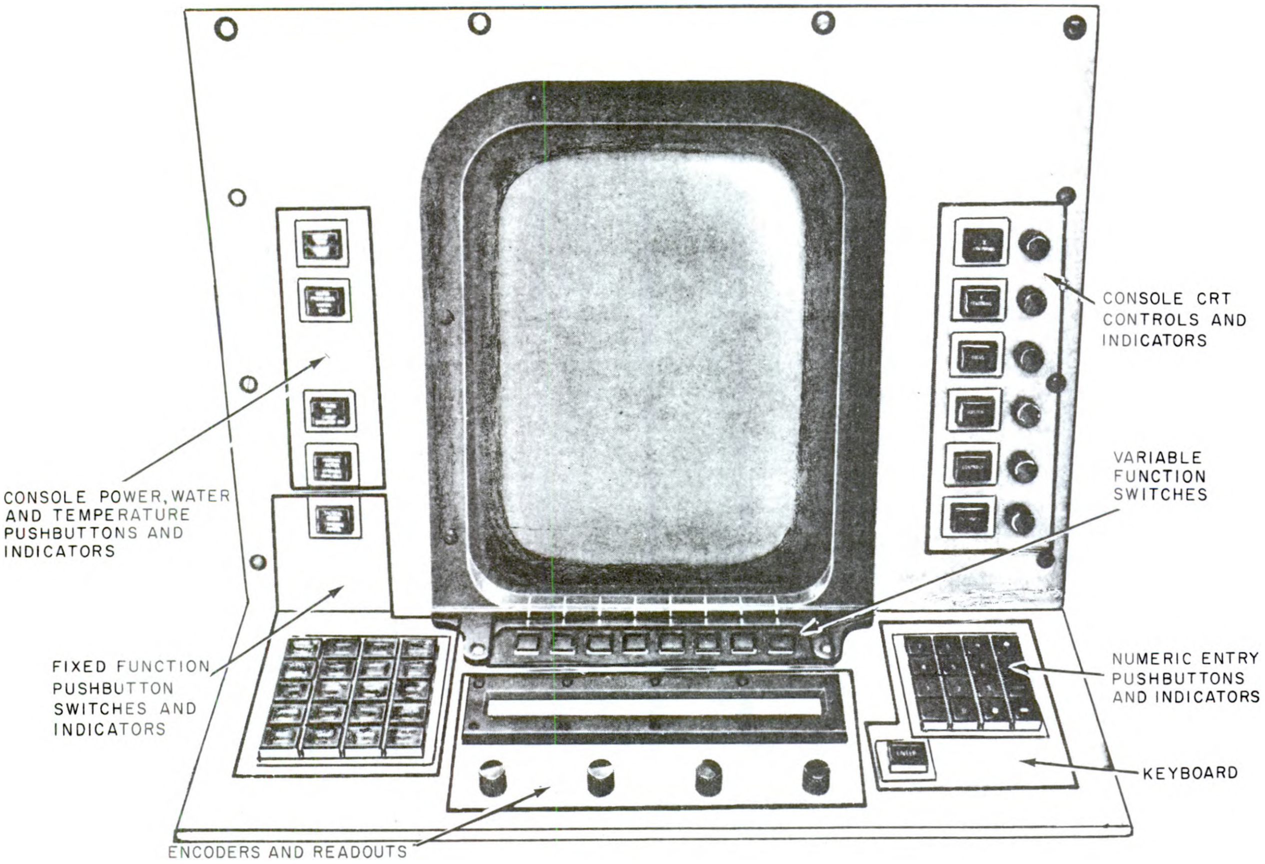
Figure 15-9.—UFCS Mk 117 and associated equipment.


CONSOLE POWER, WATER AND TEMPERATURE PUSHBUTTONS AND INDICATORS
CONSOLE CRT CONTROLS AND INDICATORS
VARIABLE FUNCTION SWITCHES
FIXED FUNCTION PUSHBUTTON SWITCHES AND INDICATORS
NUMERIC ENTRY PUSHBUTTONS AND INDICATORS
KEYBOARD
ENCODERS AND READOUTS

166.273

Figure 15-10.—Weapon control console control panel.

- Four shaft encoders permit continuous changing of the value of a designated displayed quantity. The encoders are under software control and their functions at a given time depend on the operation selected.

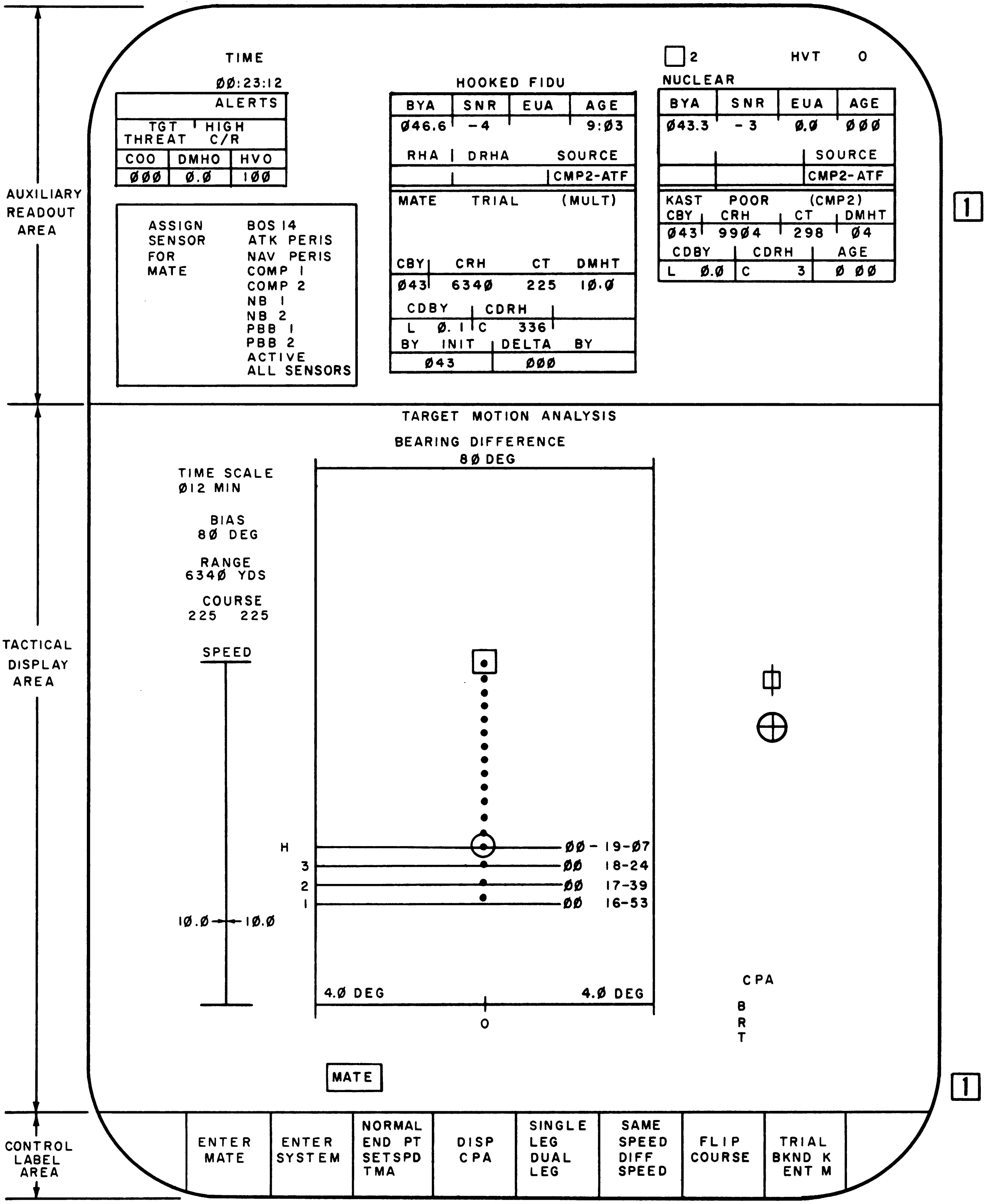
- Numeric entry switches and indicators allow the operator to edit displays by changing both text and numerics.

- Eight variable-function pushbuttons are directly below the crt. The label for each is under software control, is displayed on the crt immediately above the switch, and changes with each mode or submode selected. Thus, the program gives the eight pushbuttons numerous functions.

The crt viewing area (fig. 15-11) is divided into three areas:

1. Auxiliary Readout Area—The upper area under program control is used to display data related to ownship's conditions, target solution, approach/attack status, and system and console alerts. This area also displays other data related to the selected operational mode.

2. Tactical Display Area—The middle section is the working display. The working display, depicted in figure 15-11, is the Target Motion Analysis (TMA) mode. This mode has a single submode, Manual Adaptive TMA Evaluator (MATE), in which the operator determines target course, speed, and range by manipulating the bearings of pseudo-(trial)



166.274

Figure 15-11.—TMA mode, MATE submode, (conceptual).

target toward a visual match with actual target bearings measured by sensors.

3. Control Label Area—The lower 1-inch strip of the display displays the programmed labels of the variable-function pushbuttons. As the operator shifts modes or submodes, the labels change to provide proper functions to the selected mode or submode.

Display formats, detailed display data, and operational modes can be quickly altered by operator selection or program control, using front panel pushbuttons. Since significant operating modes and detailed formats within each mode are controlled by the computer program, great flexibility is available through software modification.

The weapon control console is constantly tested by the computer during on-line operation. Any detected error or failure, and its origin, are indicated to the operator.

ATTACK CONTROL CONSOLE

The attack control console (fig. 15-9) provides tube-by-tube control and monitoring of launcher and torpedo/missile status. The desk top (fig. 15-12) contains the firing key and groups of firing indicators and controls. This panel is called the firing panel and also contains interlock indicators and firing order and tube-selection controls.

The vertical portion of the front panel, called the tube and weapon status panel (fig. 15-13), contains tube and weapon status controls and indicators.

CONTROL PANEL

The control panel is mounted atop the attack control console as shown in figure 15-9. The control panel (fig. 15-14) provides the circuits and controls to preset nonsynchronous functions of the preset torpedo, and the indicators to monitor the status of those settings. It can independently set and monitor one port torpedo and one starboard torpedo to the same orders. The control panel also generates the voltages necessary for torpedo wire guidance.

The control panel contains five multiposition preset order selector switches with PORT and STBD SET indicators, a SET ORDER pushbutton, three power control toggle

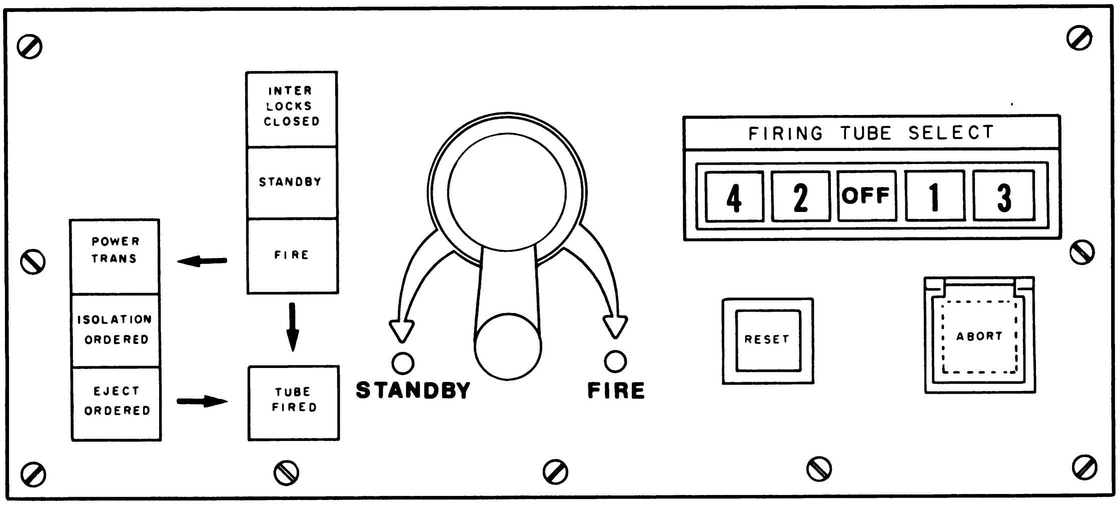


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Figure 15-12.—Attack control console-firing panel.

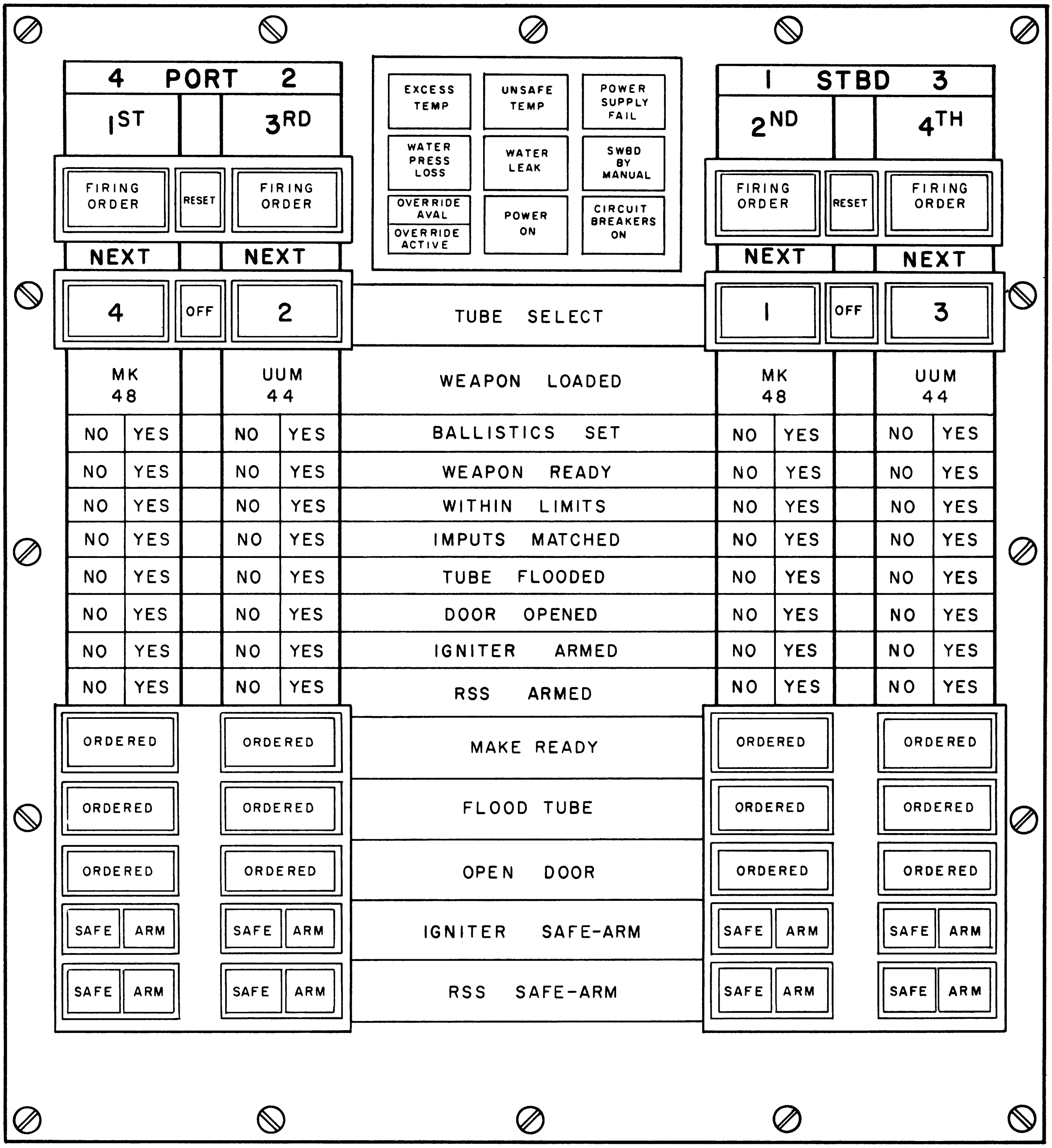

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Figure 15-13.—Attack control console—tube and weapon status panel.

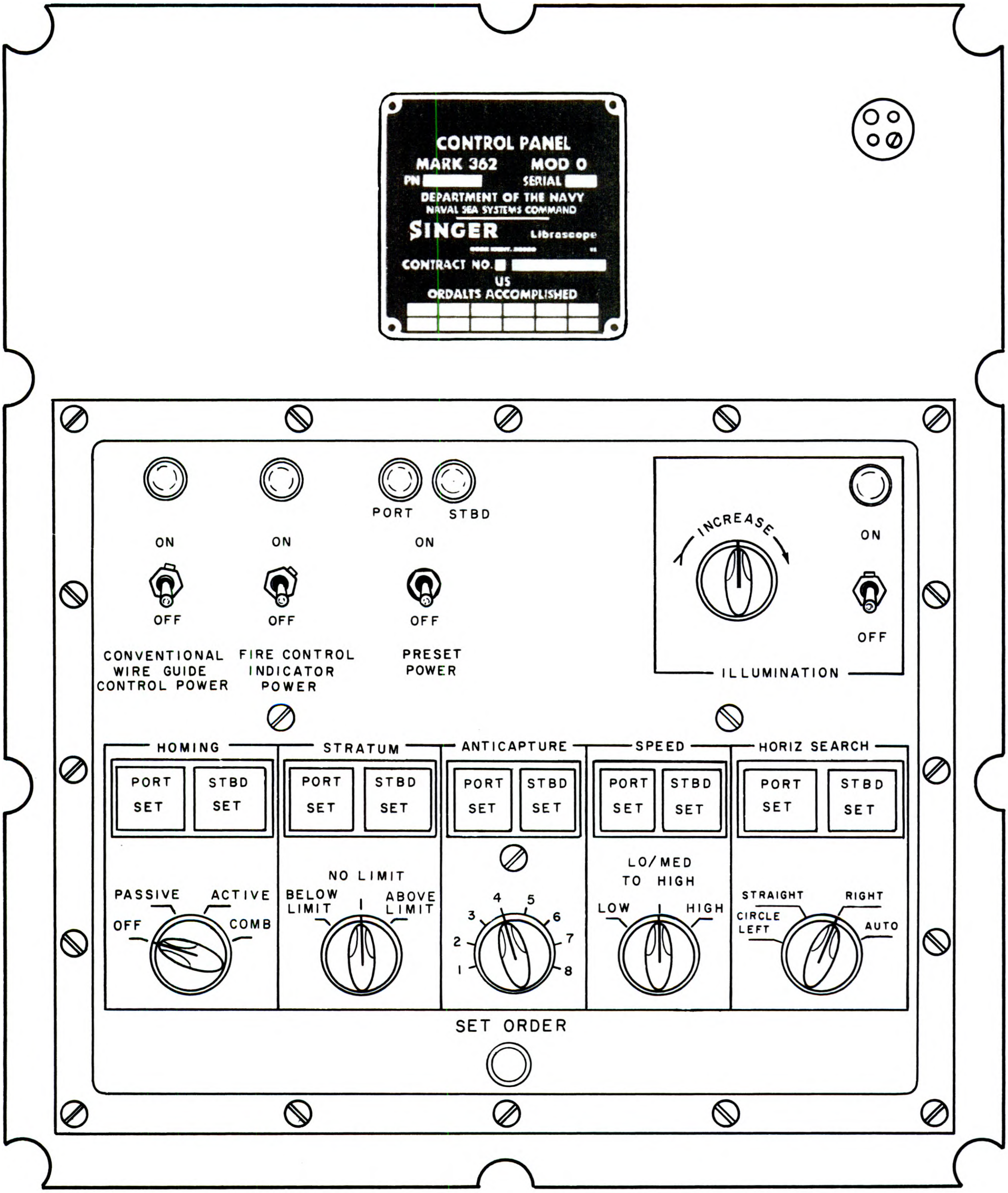

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Figure 15-14.—Control panel.

switches, and a panel illumination dimmer with a power switch.

WEAPON DATA CONVERTER

The weapon data converter (fig. 15-9) performs the analog-to-digital, digital-to-analog, and digital-to-digital conversions required by the UFCS Mk 117. The weapon data converter interfaces with the attack control console, the control panel, the attack center switchboard, the weapons launch console, and the torpedo room switchboard.

AMPLIFIER

The amplifier (fig. 15-15) amplifies the weapon data converter outputs of computed torpedo gyro angle, running depth, and enabling run. Three amplifier sections are required for

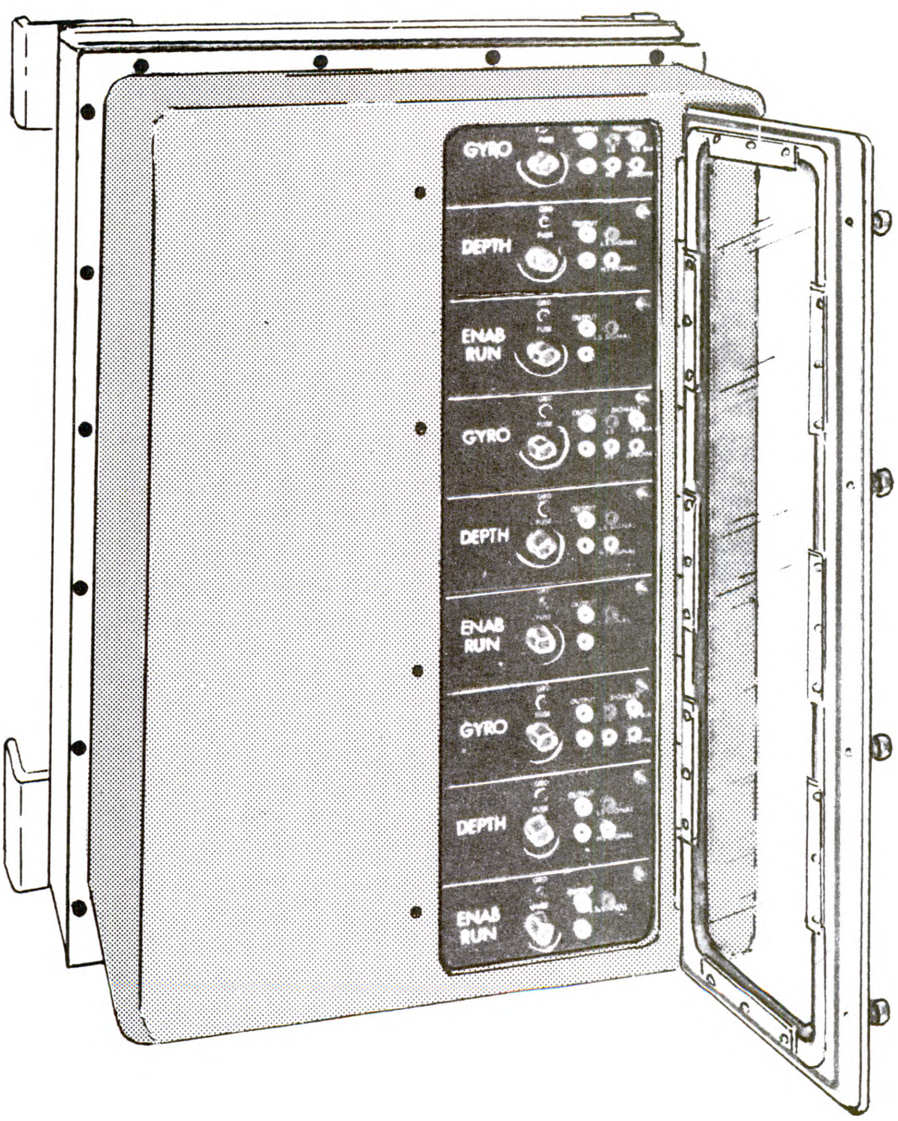

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Figure 15-15.—Amplifier.

each tube—one each for the gyro angle, running depth, and enabling run.

ATTACK CENTER SWITCHBOARD

The attack center switchboard (fig. 15-9), also called the underwater battery fire control switchboard (UBFC switchboard), is the interface information transfer element, action cutoff, and power distribution center of the UFCS Mk117. It links together the sensors, the computational elements, and the weapons.

The switchboard elements which control power and data transfers are the manual selector switches, relays, rotary snapswitches, and panel-mounted power indicator lamps and fuses.

COMPUTER EQUIPMENT

The UFCS Mk 117 computer and peripheral equipment (fig. 15-9) are installed in the attack center. The computer obtains target range and bearing data in digital format directly from the sonar systems. Target data from other ownship's sensors and ownship's motion data enter the computer via the signal data converter for use by the UFCS computer program. UFCS computer program changes and data input may be made via the input/output console. The computer program is recorded on disk in the recorder reproducer, and on magnetic tapes of the input/output console.

Computer Set

The computer set consists of two bays, each containing six units—one central processor, one input/output controller, one power supply, and three memory units. The computer set contains all the electrical and mechanical components necessary to comprise a digital computer.

Signal Data Converter

The signal data converter consists of digital processors and analog input/output signal conditioners. The signal conditioners perform, on command, three types of signal conversion:

1. Synchro-to-digital
2. Digital-to-synchro
3. Digital-to-event and event-to-digital

(An event is something that has occurred during a certain course of time—weapon ready, tube flooded, ballistics set, etc.)

Recorder Reproducer

The recorder reproducer contains all the computer programs necessary to operate and maintain the UFCS Mk 117. These programs are stored on magnetic disks. Programs such as the underwater fire control problem, training and maintenance, diagnostics, and the like, are stored here. These programs are transferred to the magnetic core memory of the computer set for operational use.

Input/Output Console

The input/output console's basic function is for computer input/output auxiliary storage. It can operate on-line and off-line. A keyboard printer is added to the input/output console along with a paper tape reader/puncher, and magnetic tape transport modules.

LEVELING COMPUTER

The leveling computer (fig. 15-9) performs the prelaunch alignment, leveling, and setting of initial conditions in the SUBROC missile inertial guidance system.

Alignment computations align the stable platform in the missile along the bearing line to the target. The closed-loop, self-leveling system compensates for ownship's roll and pitch, and stabilizes the missile platform in the horizontal plane. Position and velocity computations go to the missile as initial conditions of displacement and velocity the missile is to attain.

TORPEDO ROOM SWITCHBOARD

The torpedo room switchboard (fig. 15-9) is similar in construction to the attack center switchboard. The types of panels and switch nomenclature, however, serve torpedo room requirements. Major functions of the torpedo room switchboard panel include:

- Transforming ship's power into the voltages required by the weapon and launching system
- Controlling power to fire control elements in the torpedo room
- Weapon select switching
- Interrupt switching for SUBROC and HARPOON missiles
- Selecting the torpedo tube to receive missile preset functions

WEAPON MONITOR PANEL

The weapon monitor panel (fig. 15-8), the same as with the Mk 113 UFCS, provides weapon loaded, torpedo tube, and weapon status signals to the weapon data converter for conversion and transmission to the computer equipment and to the attack center console to provide firing panel, torpedo tube, and weapon status indications. The weapon monitor panel also controls power applied to the weapons.

MISSILE HEATER CONTROLLER

Four missile heater controllers (fig. 15-9), one for each tube, monitor the SUBROC missile gyro temperature bridges and regulate power to the missile heating elements, thus controlling the missile's internal temperature. Mark signals from the missile heater controller to the weapon monitor panel provide indications of the missile's internal temperature.

SWITCHBOX

The switchbox (fig. 15-9) provides switching of signals to the weapon. The switchbox is remote controlled and has two operational conditions, "ready" and "fire." In "ready" the switchbox transfers electrical signals to the weapon; in the "fire" the switchbox permits transmission of the start voltages to the torpedo and interrupts all other electrical transmissions.

CHAPTER 16

GENERAL MAINTENANCE

The effectiveness of the fire control equipment to which you are assigned depends largely, upon the care and attention you give to the equipment. An improperly adjusted radar, for example, can reduce the accuracy of a perfectly aligned gun battery.

The work performed on equipment falls into two broad categories: (1) actions you would take to reduce or eliminate failure and prolong the useful life of the equipment, and (2) actions you would take when a part or component has failed and the equipment is out of service. Therefore, the whole business of general maintenance can be thought of as consisting of PREVENTIVE maintenance and CORRECTIVE maintenance.

In maintenance work of any type, you must use knowledge and skills of two fundamental kinds. First, you must have SPECIFIC information, which applies only to the particular equipment that you may be called upon to repair or keep in good condition. Secondly, you must possess and use certain GENERAL skills and knowledge, which apply to many kinds of equipment and to many types or work assignments.

The specific information required consists of special procedures and processes, and detailed step-by-step directions used to maintain a particular piece of equipment. This information is supplied by the 3-M maintenance system and by publications issued by the Naval Sea Systems Command, fleet commanders, or type commanders.

The general maintenance skills and procedures are based on knowledge not contained in equipment OPs. Instead, it must be learned on the job and from rate training manuals. Information of this type forms the basic content of this chapter.

PREVENTIVE MAINTENANCE

Maintenance performed to prevent the likelihood of future troubles or malfunctions is usually referred to as preventive maintenance. This form of maintenance consists mainly of visually checking the equipment prior to and during operation, cleaning the equipment and the various components therein, lubricating, and completing performance tests.

Visual Checks

Equipment should be checked visually for loose leads, improper connections, damaged or broken components, and the like, prior to applying power to the equipment. This applies particularly to new equipment, equipment returned from overhaul, equipment which has been preserved or stored for long periods of time, and equipment which has been exposed to the weather. A close visual inspection should also be conducted on O-rings, gaskets, and other types of seals when the equipment under check is a pressurized component. This visual inspection will often reveal discrepancies that may be corrected at that time with a minimum amount of labor and parts. Such discrepancies, if left uncorrected, might result in a major maintenance problem.

Cleaning

Cleaning the equipment and the various components consists of removing dust, grease, and other foreign matter from the covers, chassis, and operating parts. This includes the removal of corrosion, fungus, and all other types of matter which could cause operating failure of the equipment. The methods used to clean the various parts and units vary, but usually a vacuum cleaner is used to remove the loose dust and foreign matter. The remainder is then wiped or removed with a clean, lint-free cloth.

If it is necessary to remove grease or other petroleum deposits, the cloth may be moistened with alcohol or dry-cleaning solvent. After the grease is removed, the part should be wiped dry, or allowed to dry by evaporation prior to applying power.

Lubrication

Lubrication of electronic equipment consists of lubricating the mechanical parts which are associated with the electronic equipment. Equipment which may need periodic lubrication (such as unsealed bearings, antenna drives, and waveguide rotating joints) should be lubricated as directed by the equipment's maintenance instructions manual. The specification number of a lubricant should be strictly followed, as the viscosity of a lubricant changes with a change in operating temperature. High operating temperatures cause lubricants to become thin, while low operating temperatures cause lubricants to thicken.

Performance Tests

A good preventive maintenance practice requires that you operate and test all equipment and instruments on a daily basis, if possible. Daily operation of the system in all modes of control exercises the servosystems, power drives, and computing networks. These exercises help to avoid some casualties and detect existing casualties.

By keeping a record of the tests, you not only will have a day-to-day reference of the system's performance, but you will be able to detect failures and malfunctions as they occur.

Some common performance tests are Transmission Checks and Daily System Operational Tests (DSOTs). When these checks or tests are conducted, the entire fire control system is manned and energized. The accuracy of data transmission is checked, as well as the response of servosystems (sluggish or erratic).

CORRECTIVE MAINTENANCE

When defective parts or unsatisfactory operation has been revealed, it is necessary to analyze the equipment, find the defective part or parts, and make the appropriate replacement, repair, or adjustment. Corrective maintenance includes those actions required to restore fire control equipment to its designed capabilities or efficiency. This includes the repair of damage produced by wear, accident, or other causes.

CARE OF OPTICAL EQUIPMENT

Optical instruments require careful handling and operation to produce satisfactory results. Only qualified personnel should operate them. Most optical equipment is hermetically sealed, and is filled with inert gas under pressure. Under no circumstances should an FT break the gas seal. Repairs affecting the internal optical systems should be accomplished only by qualified optical repair personnel.

The external optical surfaces should be cleaned with a camel's-hair brush to avoid scratching the surface. Then, use clean lens paper or chamois for wiping the optical parts. Cleaning lenses with alcohol or ether should be restricted to experienced repair personnel, as both substances will dissolve the balsam used in cementing the lenses.

External mechanical moving parts should be lubricated periodically in accordance with a prescribed program. Care should be exercised, as oil or oil vapor must never reach the lenses.

You should protect optical equipment from weather and spray when possible. Also, the optics should not be exposed to the direct rays of the sun unless necessary during operation. End windows and operating knobs should always be protected by their covers when the instrument is not in use.

You should make a periodic inspection by looking through both ends of the optical system.

Be on the lookout for silver plating peeling from the mirror surfaces, dust and dirt, moisture fogging, and pitted or discolored lenses. Gas-filled optics should be regassed periodically.

ROUTINE ELECTRICAL MAINTENANCE

In both preventive and corrective maintenance, your first step should be a thorough visual inspection. Such an inspection should reveal any improper soldering, loose connections, or broken leads. It will also disclose any overheating which results in charred, discolored, or blackened terminals, connectors, or leads. Another step in the maintenance of electrical components is to check for normal operation.

ROTATING MACHINERY

Rotating machinery should be inspected and cleaned at prescribed intervals (periodic checks) and whenever repairs to the machinery have been made. For such cleaning and inspection, the following procedure is suggested.

1. Unfasten and remove the end cover.
2. Remove dust and dirt from the machine and end covers, using clean, dry, compressed air or a soft brush.
3. Loosen, gently remove, and inspect the brushes, being extremely careful not to nick or mar their edges. Note the location and position from which each is removed so that it can be replaced in exactly the same position.
4. Check commutators or sliprings for excessive wear, pitting, dirt, thrown solder, or other defects. A highly polished commutator or slipring is desirable, but a dark-colored one should not be mistaken for a burned one. If the surface is dirty, clean it with a lint-free cloth moistened in a cleaning solution (Specification PS-661) and wipe dry. Avoid fingermarking the commutator or slipring surface.
5. Secure all brushes in their holders, making certain they are replaced in exactly the position from which they were removed.
6. Replace and secure end covers.

Sliprings

Sliprings are solid metal rings mounted on the rotor of an alternating current machine for transferring the power to or from external circuits through brushes or wipers. Sliprings are also used on synchros, director connections, and stable element connections.

While they vary in size and design, the maintenance of sliprings is essentially the same for all types. They should be inspected periodically for wear, grooving, and cleanliness. Normally, the surface of the rings should be bright and smooth.

As mentioned previously, the connection to the rings is by brushes or wipers. Wiper contacts are used with devices that do not require high current and consequently require only light pressure when making contact. Excessive pressure will result in excessive wiper wear, because the wiper contact is usually of a softer material than the rings. Any contacts showing considerable wear should be replaced.

If sliprings are inspected and found rough, scratched, or grooved, corrective action must be taken. They can be smoothed with a fine crocus cloth; however, care should be exercised not to cause high and low spots which would interfere with high speed operation. Further repairs, such as cutting with a lathe, should be performed at overhaul activities (Navy yards and tenders). Also, in cleaning with a solvent, be careful not to allow the solvent to enter the bearings, since the solvent cuts oil or grease. This, of course, would cause the lubricant to flow out of the bearing.

Commutators

Commutators have been called the "soft spot" of d.c. machinery because they require considerable maintenance. The commutator is a series of copper segments separated by an insulator. When the brushes make contact with a pair of segments, an armature coil is connected into the circuit. Thus, when the motor or generator is moving, the brushes and commutator switch coils in and out in the proper sequence.

The normal appearance of the commutator is a shiny, smoothly worn, chocolate brown color. A blackened or pitted commutator is caused by poor brush and segment contact, open or shorted coils, overloads, and the like. If the brushes are causing the blackened appearance, they should be replaced and then the commutator should be cleaned. Cleaning is accomplished by the use of fine sandpaper and the recommended solvent. The sandpaper should be held against the commutator by a piece of wood that is grooved to fit the commutator. NEVER USE EMERY CLOTH. Emery is an electrical conductor, which would cause a short circuit.

When the fault is other than brush and segment contact, that is, a short or open coil, the machine should be replaced and sent to overhaul. Another fairly common defect is HIGH MICA. As the copper of the commutator wears down, the mica, which is the insulation separating the segments, does not. Consequently, it may be higher than the segments. The high mica gives a bounce to the brush every time it passes underneath; this results in arcing, because the brush is constantly breaking contact. High mica can be spotted by rubbing your fingernail over the surface of the commutator. There should be a small depression between each segment. If there is high mica, this depression disappears. Undercutting is the remedy for high mica, and this operation is normally reserved for the overhaul activities.

Brushes

Brushes are found in numerous sizes and shapes and are made of various materials and compounds. Many brushes used in fire control equipment are made of graphite or some other form of carbon. In all probability, the majority of the maintenance you will perform on rotating machinery will be concerned with brushes. Brushes should be checked for wear, chipping, oil soaking, sticking in the brush holders, spring tension, length, and area of contact with the commutator. If for any reason a brush is removed and is to be replaced, it should be marked or tagged so it may be replaced in the same brush holder in the same position it occupied before removal.

Brushes that show excessive or improper wear or chipping, or are oil soaked, should be replaced. Care should be exercised in obtaining the correct replacement. It is important that the brushes be changed before they are completely worn away in order to prevent damage to the equipment in which they are used.

A brush is sometimes marked to indicate allowable wear by a readily noticeable groove in the edge. This groove extends from the top of the brush down to a point that is 75 percent of the brush wearing depth. (The top is the end opposite the wearing face.) Thus, if the brush is worn down to the groove, it must be replaced. If no groove is present, consult the equipment OP for acceptable minimum brush lengths.

In the replacement of brushes, you will find that some new brushes are ready to use. That is, the brush face is slightly concave so that it fits tightly on the commutator. Other new brushes are NOT ready to use; they must be sanded in. This sanding, or seating, can be accomplished by wrapping fine sandpaper around the commutator. The paper is placed sand side up with a lap following the direction of normal rotation of the device, and is held in place by a rubber band. Do NOT use glue or tape. The brushes are placed in their holder under spring tension, and the armature is rotated slowly by hand in the direction of normal rotation. In so doing, the contact surfaces of the brushes are sanded until their curved surfaces match the curvature of the commutator. The carbon dust from the brushes must be removed from the device by using dry compressed air followed by cleaning with a solvent.

MAINTENANCE TECHNIQUES

Soldering

The correct procedure for soldering is given in *NEETS Module 4, Introduction to Electrical Conductors, Wiring Techniques, and Schematics.* Therefore, it is not covered here. Let us consider for a moment the end product—properly and improperly made soldered joints.

A good, well-bonded connection is clean, shiny, smooth, and round. It shows the approximate outline of the wire and terminals. The wire and terminals are completely covered, and the solder adheres firmly. The insulation is close to, but not in, the hole or slot; it is approximately 1/8 inch from the terminal. It is not charred, burned, nicked, or covered with rosin. A film of rosin may remain on the joint and need not be removed unless the joint is in a high-frequency circuit or unless fungusproofing is anticipated.

Soldered joints may be defective for a variety of reasons. Following are a few examples.

A COLD solder joint has a dull appearance and a crystallized texture. Because of the poor union between the wire and terminal, the joint in time develops a high resistance as the metals oxidize. This type of joint is caused by insufficient heat during soldering, and may be repaired by reheating.

A ROSIN joint is so named because the wire is held by rosin rather than solder. The flux is spread over the terminal, and instead of the solder bonding with the terminal, the solder settles on top of the rosin. The joint may have all the appearances of a good joint, but a little pressure causes movement or an ohmmeter indicates an open. A rosin joint occurs when using a "cold" iron or one that is too small. In most cases, merely applying a hot iron will clear up a rosin joint.

A DISTURBED solder joint has an irregular or crystallized appearance and the solder may be chipped off with a fingernail or a pointed tool. It is caused by the wire being moved before the solder has fully set. It may be repaired in the same manner as the cold solder joint.

An INSUFFICIENT solder joint can introduce high resistance in the circuit and, as current flows, undesirable heat. It may loosen and cause an open or intermittent operation depending upon the amount of oxide present. This heat or a visual inspection may reveal this condition, but it may be necessary to use an ohmmeter to detect this type of solder joint. To repair it, it should be taken apart, cleaned of oxide, and resoldered correctly.

A NO-SOLDER joint may cause noise due to oxide or vibration, or the circuit may open entirely. A visual inspection and an ohmmeter check should indicate this condition. The joint should be taken apart, cleaned, and then resoldered correctly. There are many other soldering defects, such as excessive solder, loose solder, and insulation too close or too far from the joint. Corrective action in some instances may be a matter of judgement.

Occasionally, some special techniques are required in soldering. Such an occasion occurs in fire control equipment using miniaturized components. In such equipment, the physical dimensions of resistors have greatly decreased and application of a soldering iron close to the body of these small carbon composition resistors causes a PERMANENT change in resistance. Overheating of these resistors and other components during soldering can be avoided only by restricting heat conduction along the terminating leads.

The most acceptable means of preventing this overheating is by use of a thermal shunt (fig. 16-1). This shunt should be placed as close to the resistor and as far from the joint as possible. Be certain that the clamp does not contact both the resistor and the joint. If you don't have a clamp type shunt, and don't have time to make one, you can use small needlenose pliers. If you wrap a rubber band tightly around the handles, the pliers will grip the resistor lead so that you won't have to hold them in place while you solder.

Crimping

The crimp-on or solder less terminals require relatively little operator skill. Another advantage is that the only tool necessary is the crimping

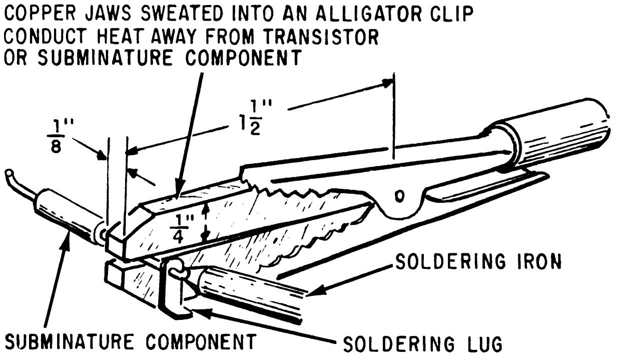

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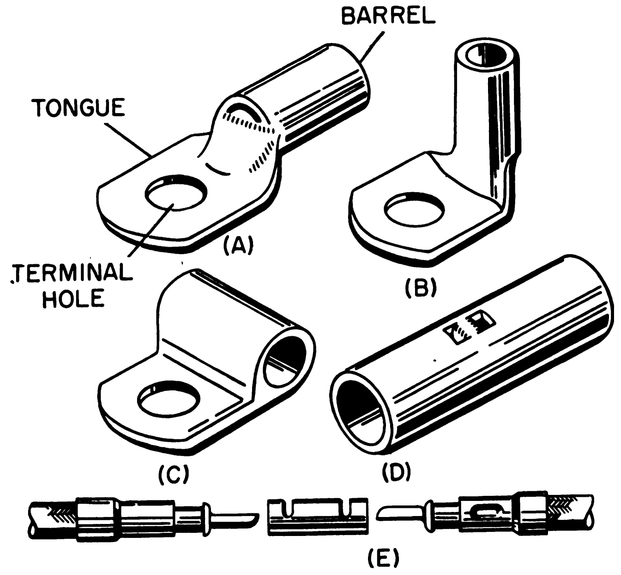
Figure 16-1.—Details of a thermal clamp type of shunt.

tool. The connections are made rapidly, and they are cleaner and more uniform. Due to the pressures exerted and the materials used, the crimped connection or splice, properly made, has an electrical resistance that is less than that of an equivalent length of wire.

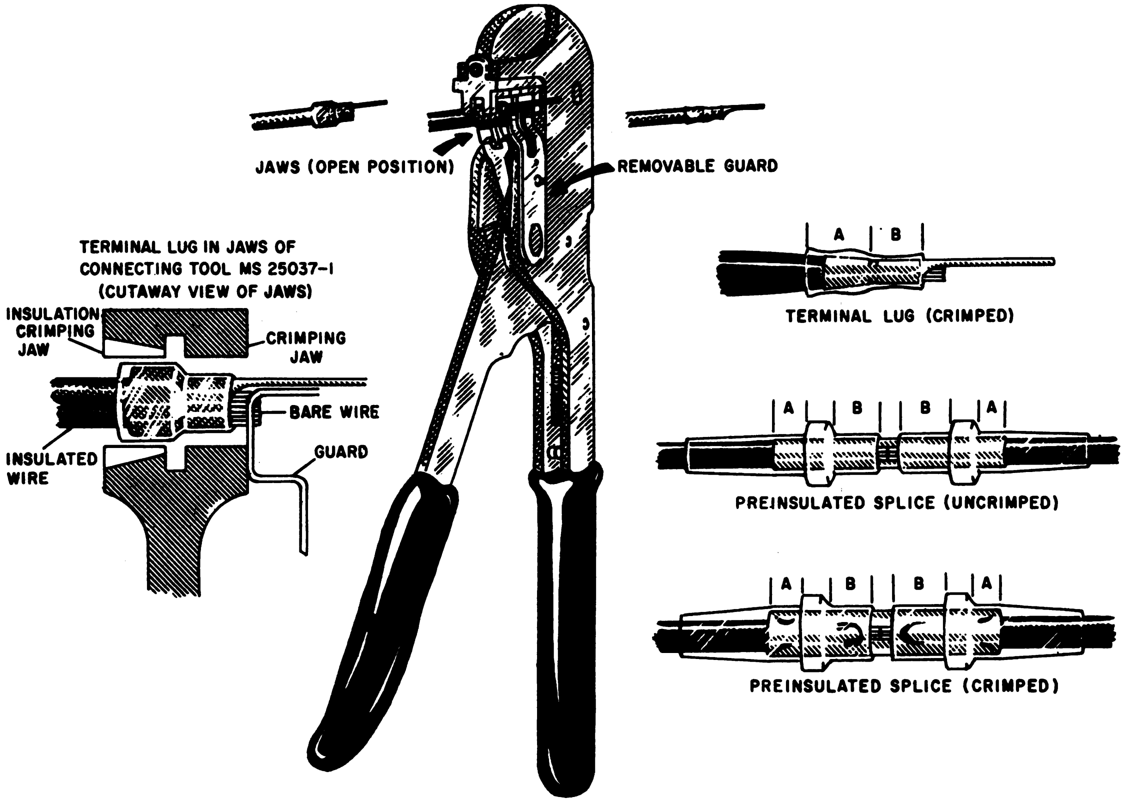
The basic types of terminals are shown in figure 16-2. A shows the straight type, B the right-angle type, C the flag type, D the splice type, and E the disconnect-splice type. There are also variations of these types, such as the use of a slot instead of a terminal hold, and three- and four-way splice types of connectors.

Various sizes of terminal or stud holes are found for each of the different wire sizes. A further refinement of the solderless terminal is the insulated terminal; the barrel of the terminal (fig. 16-2) is enclosed in an insulation material. The insulation is compressed along with the terminal barrel when crimping, but is not damaged in the process. This eliminates the



12.244

Figure 16-2.—Basic types of solderless terminals.

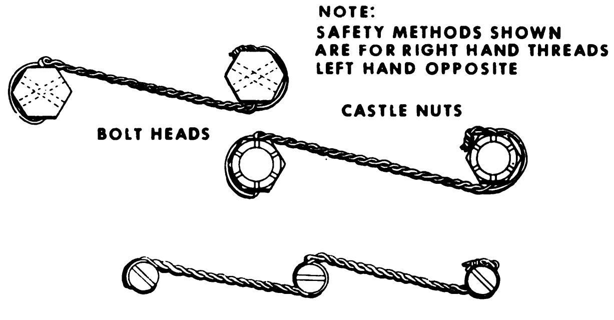

JAWS (OPEN POSITION)
REMOVABLE GUARD
TERMINAL LUG IN JAWS OF CONNECTING TOOL MS 25037-1 (CUTAWAY VIEW OF JAWS)
INSULATION CRIMPING JAW
CRIMPING JAW
BARE WIRE
INSULATED WIRE
GUARD
A
B
TERMINAL LUG (CRIMPED)
A
B
B
A
PREINSULATED SPLICE (UNCRIMPED)
A
B
B
A
PREINSULATED SPLICE (CRIMPED)

207.38

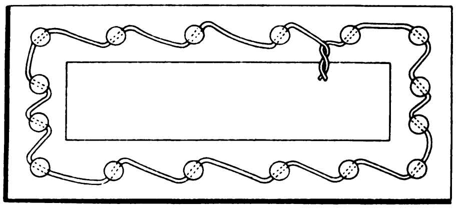
Figure 16-3.—Crimping tool.

necessity of taping or tying an insulating sleeve over the joint.

The standard crimping tool (fig. 16-3) employs a double jaw to hold the terminal or splice. One side of the jaw applies crimping action to fasten the terminal to the bare wire when the terminal is inserted, as shown on the left in figure 16-3. When the tool is used correctly, a deep crimp is placed in the B area of terminal lugs and splices, as shown in the diagrams on the right in figure 16-3. A shallow crimp is applied to the portion of the terminal or splice which extends over the insulation of the wire, as indicated by the A area in each diagram. This clamping action is provided by a recessed portion in the other side of the divided jaw. A guard, which should be in the position shown when crimping terminals, aids in proper positioning of the terminal. However, the guard must be moved out of the way when the tool is used for crimping splices.



DOUBLE-TWIST METHOD
(A)



SMALL SCREWS IN CLOSELY SPACED
CLOSED GEOMETRICAL PATTERN
SINGLE WIRE METHOD
(B)

228.42
Figure 16-4.—Safety wiring nuts, bolts, and screws.

Safety Wiring

Some equipment parts require a positive safety locking device. The use of safety wire is one accepted method of providing this safety measure. A common application of safety wire is the tying together of nuts, bolts, screws, and connector parts to prevent them from coming loose due to vibration.

The most common method of safety wiring nuts, bolts, and screws is known as the double-twist method (fig. 16-4A). The twisting may be accomplished by hand, or special safety wire pliers may be used. If the twists are made by hand, the final few twists should be made with pliers to apply tension and secure the ends of the wire properly. The safety wire should always be installed and twisted so that the loop around the head stays down and does not tend to come up over the bolthead, causing a slack loop. Extreme care must be used when twisting the wires together to ensure that they are tight but not overstressed to the point where breakage will occur under a slight load or vibration. Always use new safety wire on every job and take care to use pliers only on the ends of the wire so as not to nick the wire. If safety wire becomes nicked, discard it and use a new piece. When the final twists are made with pliers, cut off the loose ends that have been nicked by the pliers and bend the end of the wire around the bolt or screw head to protect personnel from the sharp ends.

The single-wire method of safety wiring (fig. 16-4B) may be used on small screws in a closely spaced area, provided the screws form a closed geometrical pattern. Note that any loosening tendencies pull against the tension of the wire. Never "back off" or overtorque in order to align holes for safety wiring.

You should safety wire electric connectors only when specified on engineering drawings or when your experience has shown the connector does not stay tight. Electric connectors are usually safety wired in areas of high vibration, and in locations not readily accessible for periodic maintenance inspection.

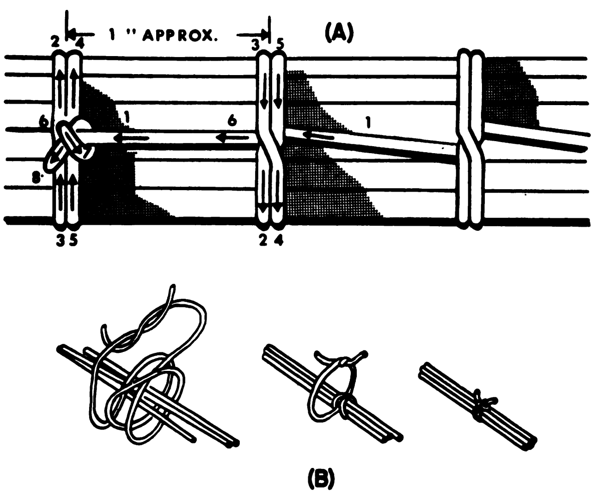
When it is necessary to safety wire electrical connectors, use 0.032-inch-diameter wire wherever possible. On small parts with holes 0.045-inch-nominal-diameter wire or smaller, use

0.020-inch-diameter safety wire. If the connector to be safety wired does not have a wire hole, remove the coupling nut and drill a No. 56 (0.046-inch-diameter) hole diagonally through the edge of the nut. Figure 16-5 shows a proper safety-wired connector.

Tying and Lacing

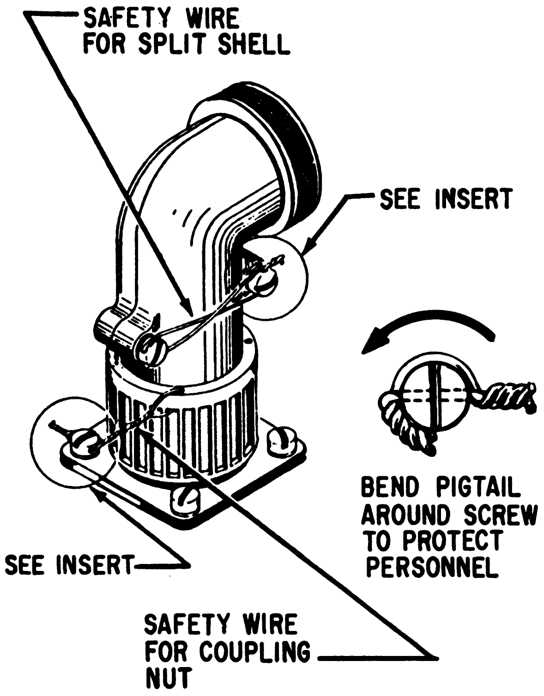
While making repairs or fabricating a new cable, you may find it necessary to tie or lace the cable. The accepted method for lacing cable harnesses is shown in figure 16-6. The use of the continuous lacing method is restricted to panels and junction boxes. The purpose of lacing is to keep all cables neatly secured in groups and to avoid possible damage from chafing against equipment or interference with equipment operation. When continuous lacing (fig. 16-6A) is used, it is not to include cables of more than one harness group.

Continuous lacing is restricted in its use because of the tendency of the lacing to unravel if the cord is broken. In place of continuous lacing, tying (or short-section lacing) is used. This method of tying is shown in figure 16-6B. In this method, a clove hitch is tied about the wires. Then, a half hitch is tied over the clove hitch in such a manner as to produce a square knot.



12.247

Figure 16-6.—Lacing and tying.



228.42A

Figure 16-5.—Safety wiring a connector.

Shielding and Bonding

Shielding is the enclosing of cables or electrical units in metal to prevent high-frequency interference. Shielding causes the high-frequency voltage to be induced in the shield rather than in the units or cables. Shielding is used where a unit is to be protected from radio-frequency noise. It is also used to keep cables or units from emitting radio-frequency noise.

Where shielding of cables is used, it is very important that it be well grounded. Radiating circuits such as pulse cables and transmission lines use coaxial cables. The outer flexible conductor of "coax" often serves as the shield, but occasionally an additional braid is used for shielding. Regardless of the system used, the conductor forming the shield is grounded.

Disturbances caused by spark discharges are the most difficult to control. A spark discharge not only radiates but also causes voltage variations in the circuit. Shielding is effective for the radiations but not for the line variations. These variations in the line can be smoothed out by the use of filters. The function of such filters is to block or bypass voltages and currents of frequencies which would cause interference.

Bonding straps are used to tie together, electrically, any parts of an equipment or system which are insulated from the ship's structure.

Some of the reasons for bonding are as follows:

1. To minimize interference to electronic equipment by equalizing the static charges that accumulate
2. To provide a proper "ground" for electronic equipment
3. To provide a low-resistance return path for single-wire electrical systems
4. To aid in the effectiveness of shielding

A bond is usually made of a flexible metal strap provided with a crimped-on terminal at each end.

The bond must be intact and make a good electrical connection at all times. In replacing a bond, you should be careful to make a good metal contact. Place bonds in such a position that they will not interfere with the operation of the unit and will not be damaged or broken loose because of the motion or vibration of the unit.

Shock Mounts

Electronic equipment is sensitive to mechanical shock and vibration; therefore, units of electronic equipment are normally shock mounted to provide some protection against vibration.

Periodic inspection of shock mounts is required, and defective mounts should be replaced with the prescribed type. If you are the inspector, the main factors that you should look for are chemical deterioration of the shock-absorbing material, stiffness and resiliency of the material, and overall rigidity of the mount.

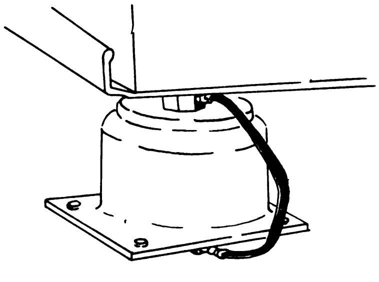
Shock-absorbing materials commonly used in shock mounts are usually electrical insulators. For the sake of safety, it is required that each electronic unit mounted in this manner must be electrically bonded to a structural member of the ship (fig. 16-7). The bonding strap should also be included in the inspection of the shock mounts, and defective or ineffective bonds should be replaced or reinstalled.

REPAIR OF FIRE CONTROL INSTRUMENTS

Reliability is designed into fire control equipment. With proper care, the equipment will give long years of service. Each instrument undergoes a series of tests before the Navy accepts it. It is installed by experts; and before the ship accepts the equipment, it must work at designed efficiency. It is your job to maintain the peak performance of the equipment to which you are assigned.

The attitude you assume toward your equipment will govern your maintenance behavior. This equipment deserves your respect. Think of the job the fire control system does, and how it does it, often under adverse conditions. The equipment, in many instances, is of intricate and delicate design and has a high degree of accuracy.

The first requirement in any maintenance program is to know the equipment. This knowledge can be obtained from the OPs on the equipment, tests and checks held during preventive maintenance, and operation of the equipment. When the equipment is working correctly, study its performance in all modes of operation. As indicated earlier, a firm grasp of the fundamentals is essential. As pointed out,



228.39

Figure 16-7.—Shock mount, bonding.

knowledge of this nature can be obtained from the rate training manuals.

The majority of casualties can be corrected by minor repairs. Quite frequently, the hardest part of the repair job is to find the fault. Before going into an instrument, you should check its operation in all modes of control. Run all likely tests. Take full advantage of the test features designed into the equipment. If there is an alternate supply, or if an input can be received from a different source, try it.

Before beginning the actual repair, be sure of your facts. Take your time and think; do not jump to conclusions. Resist the temptation to learn more about the casualty by prematurely disassembling or adjusting the instrument. An instrument loses some of its precision each time it is disassembled. Adjustments are provided to compensate for changes in the values of associated components. This is normally due to wear, age, or environment. Adjustments are not there to correct casualties. Do not make an adjustment unless you are sure it is the correct step.

Remember, the equipment worked before the casualty occurred. Therefore, a change to the original wiring or installation will not help.

Another factor to consider is your test equipment. It should be checked before using. Test equipment is discussed later in this chapter. Before we proceed, however, lets look at some additional repair considerations.

Frequently the easiest way to check a suspected component is by substitutions (easter egging) it just might increase your trouble. Before you replace a component, make sure the replacement is good, and is identical to the original component.

When you find that a defective component has caused the casualty, check the circuits to and from the component. The component may have broken down due to normal usage; on the other hand, another casualty may be present which caused the breakdown, or was caused by it. The check of the circuits to and from may uncover any additional casualties.

Only after you have completely exhausted all other possibilities and have a good idea of where and what the trouble may be should you disassemble a piece of equipment. It is embarrassing, to say the least, to be in the middle of disassembling an instrument and find that the trouble is a blown fuse.

Follow step by step the disassembly and reassembly procedures in the OP. Do not take shortcuts, and do not get ahead of yourself. This is a natural tendency when you are familiar with the instrument and become overconfident. Review the procedure at each step, and study the next step carefully.

Do not leave hardware (nuts, bolts, screws, washers, spacers, and the like) adrift. Each piece of hardware has a particular job to do; without it, the job is not done.

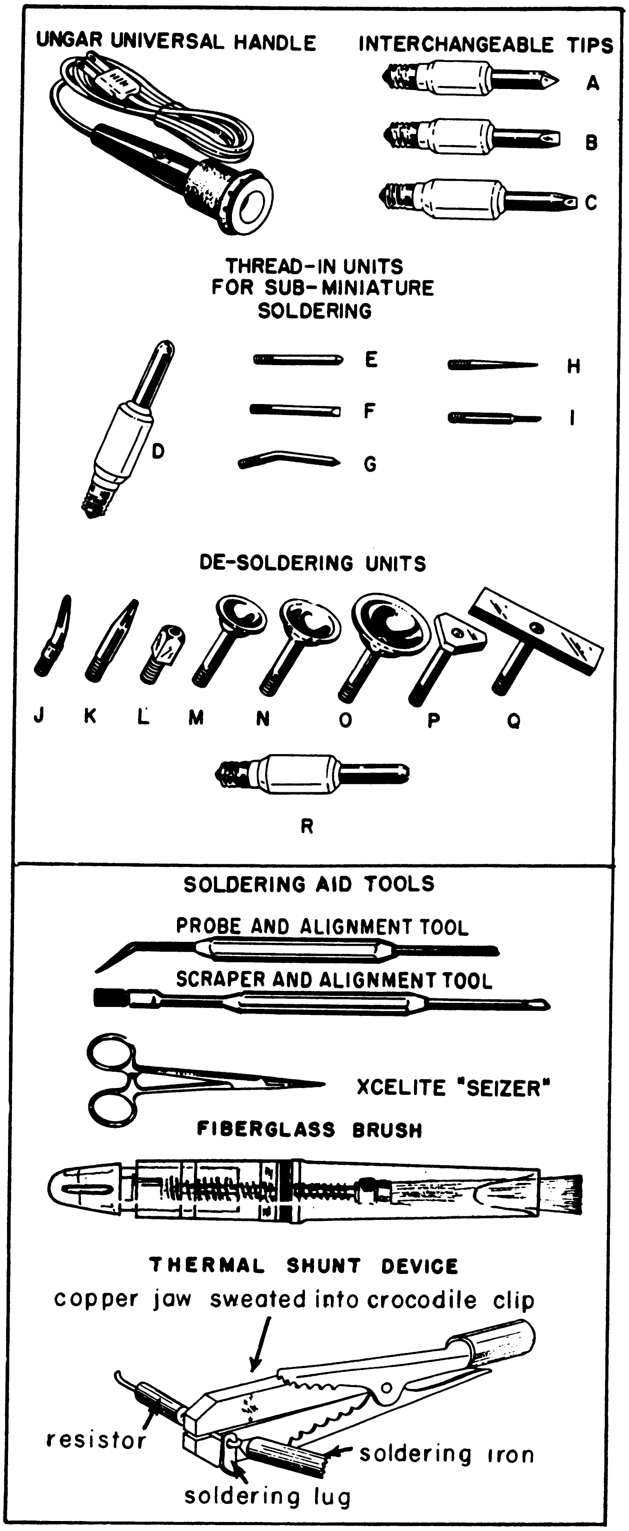
Safety features are built into the equipment for your protection. Do not bypass them. But, if you must, be sure of your grounds. In some electronic equipment the chassis is grounded to the cabinet. When removed from the cabinet and placed on an insulation material, the ground is lost. In this case, much to your discomfort, you might furnish the ground connection.

TROUBLESHOOTING PRINTED CIRCUITS

Locating components and circuit tracing in a printed circuit is generally easier than in wired circuits. The mass of wiring, terminal strips, and obscured test points are virtually eliminated. The components in a printed circuit are grouped in an orderly manner. Special tools and techniques are used in working on printed circuits and electronic modules. In this discussion, we use transistors as the representative components.

SPECIAL TOOLS AND TECHNIQUES

To avoid overheating and damaging the transistors and other semiconductor devices, a small, low-wattage (50 watts or below) soldering iron with a narrow point or wedge must be used. An iron with interchangeable tips, such as the one illustrated in figure 16-8, satisfies most soldering requirements.



Item	Description
Soldering Iron	
A	Pyramid tip, 5/16" diameter
B	Chisel tip, 3/8" diameter
C	Chisel tip, 1/4" diameter
D	Thread-in element for thread-in tips
E	Thread-in straight cone tip, 3/8" diameter for element D
F	Thread-in straight chisel tip, 3/8" diameter for element D
G	Thread-in bent cone tip, 3/8" diameter for element D
H	Thread-in straight needle tip, 3/8" diameter for element D
I	Thread-in micro tip for element D
De-soldering Units	
J	Thread-in offset slotted tiplet for element R
K	Thread-in straight slotted tiplet for element R
L	Thread-in hollow cube tiplet for element R
M	Thread-in 5/8" diameter cup tiplet for element R
N	Thread-in 3/4" diameter cup tiplet for element R
O	Thread-in 1" diameter cup tiplet for element R
P	Thread-in 5/8" diameter triangle tiplet for element R
Q	Thread-in 1-1/2" x 3/8" bar tiplet for element R
R	Thread-in element for de-soldering tiplets

70.121

Figure 16-8.—Recommended special tools and aids.

Soldering Techniques

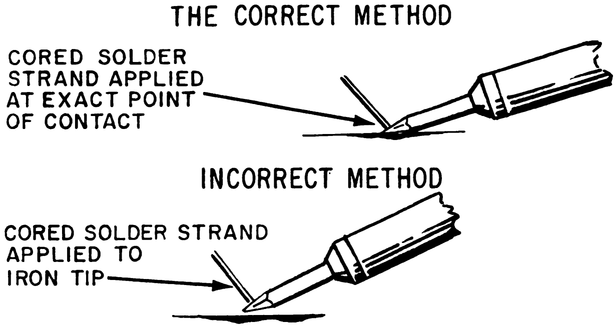
When it is necessary to solder or desolder a transistor or other semiconductor device, use a clean, well-tinned pencil soldering iron and a good quality, low-temperature solder. Complete the soldering process as quickly as possible.

In the application of solder, remember that the iron must heat the metal to solder-melting temperature before actual soldering can take place. The flat side of the soldering-iron tip should be held directly against the parts to be soldered. The solder-melting temperature should be reached in a matter of seconds (5 to 10 seconds), therefore, the soldering iron and the solder strand must be applied simultaneously. Apply the solder to the point of soldering-iron contact—not to the soldering iron. Figure 16-9 illustrates both the correct and an incorrect manner of solder application.

Be sure the terminal, lead, or any portion of a part to be soldered has been properly cleaned and tinned before positioning it for soldering. Do not tin printed-circuit terminals; clean moisture, grease, or wax from the printed ribbon with a stiff-bristle brush and an approved solvent.

Desoldering

The Ungar offset or straight slotted tiplets (J and K, fig. 16-8) simultaneously melt the solder and straighten the leads, tabs, and small wires bent against the board or terminal, as illustrated in figure 16-10A.


THE CORRECT METHOD
CORED SOLDER STRAND APPLIED AT EXACT POINT OF CONTACT
INCORRECT METHOD
CORED SOLDER STRAND APPLIED TO IRON TIP

70.123

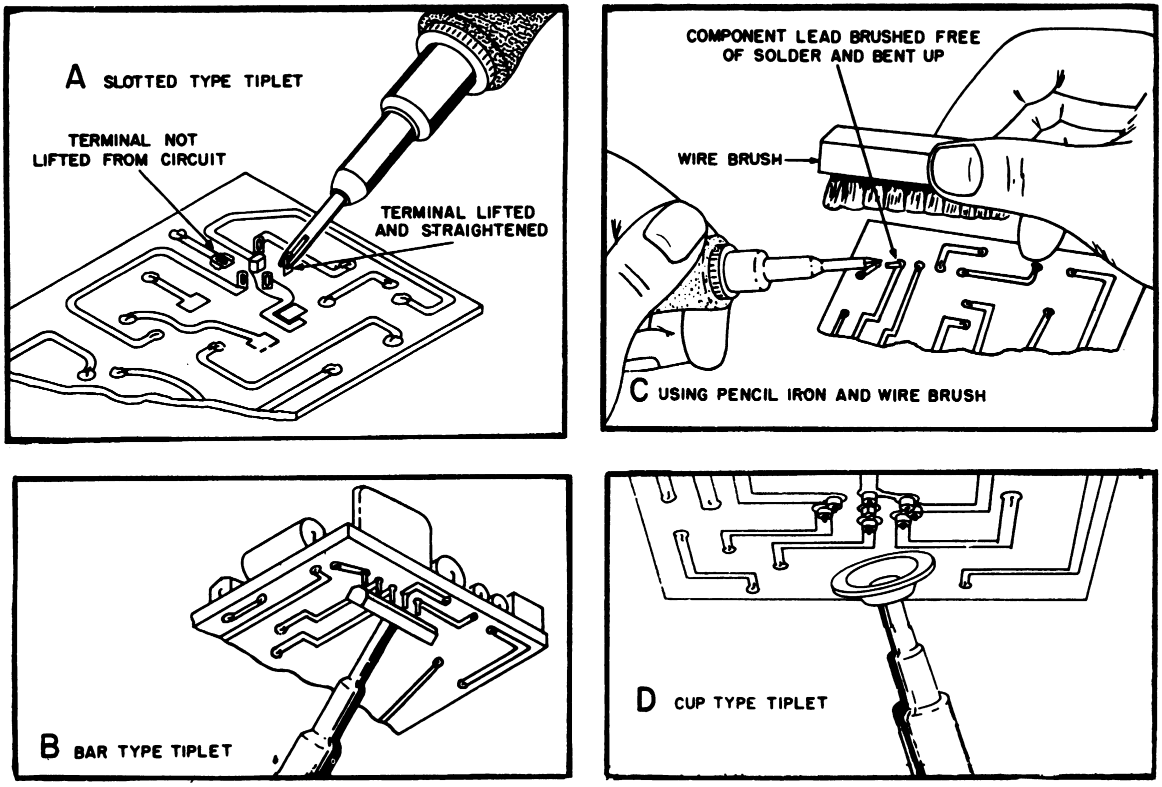
Figure 16-9.—The correct and incorrect methods of solder application.

The bar type of tiplet (Q, fig. 16-8) removes straight-line, multiterminal parts quickly and efficiently, as illustrated in figure 16-10B. The removal of this type of part may be accomplished by individually heating each solder connection and brushing away the melted solder with a wire brush, as shown in figure 16-10C. When this method is used, particular care must be taken to prevent loose solder from making contact with other parts or with the circuit board where it may possibly cause a short circuit. Care must be exercised to ensure physical contact with the terminals to be desoldered and nothing else. Do not allow the tool to remain in contact with the connection for prolonged periods of time. Remove the tool after a short time, wipe off the excess solder, and then reapply. This permits the area to cool, thus protecting the circuit board and associated parts.

The cup-shaped tiplets (M, N, and O of figure 16-8), the triangle tiplet (P of figure 16-8), and the hollow-cube tiplet (L of figure 16-8) are specially designed to withdraw solder from the circular or triangular mounted parts in one operation. The use of a cup-shaped tiplet is illustrated in figure 16-10D. The tiplets must be applied with care to the terminals of the part to be removed, so as not to touch the circuit board or its associated parts.

Transistor Replacement

To replace a proven defective transistor, first cut all of its leads, and then remove it from the assembly. Transistors are mounted on circuit boards in many different ways; thus, it is necessary to study how a particular transistor is secured before attempting to remove it. A transistor with a clamp type of mounting requires only a pointed tool between the clamp and the transistor to remove it. A transistor mounted in a socket may have a wire or spring around it. Remove this clamp before pulling the transistor out of the socket. In some instances the transistor is bolted through the board. Remove the nut and washer, and then remove the transistor. Where vibration is a prime factor, the manufacturer mounts the transistor through

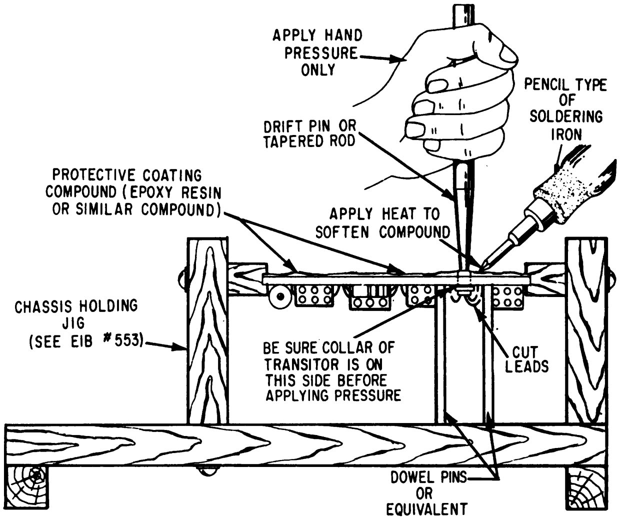

A SLOTTED TYPE TIPLET
TERMINAL NOT LIFTED FROM CIRCUIT
TERMINAL LIFTED AND STRAIGHTENED
COMPONENT LEAD BRUSHED FREE OF SOLDER AND BENT UP
WIRE BRUSH
C USING PENCIL IRON AND WIRE BRUSH
B BAR TYPE TIPLET
D CUP TYPE TIPLET

70.124

Figure 16-10.—Special soldering iron adaptations.

the circuit board and bonds it (with epoxy resin or a similar compound). For this type, a flat-ended, round-rod type of tool (drift punch) of a diameter less than that of the transistor case is required. Place the printed circuit board on which the transistor is mounted in a chassis holding jig, in such a way that pressure exerted against the board will be relieved by proper support on the other side, as shown in figure 16-11. Apply a hot-pencil soldering iron to the bonding compound, and simultaneously apply the drift punch against the top of the transistor, exerting enough pressure to force the transistor from the softened compound and on through the board, as indicated in figure 16-11.

Before installing the new transistor, you must take great care to prepare the part for installation. Test the transistor in a transistor tester before installing it. This precaution will assure that the transistor is good before it is installed. Preshape and cut the new transistor


APPLY HAND PRESSURE ONLY
PENCIL TYPE OF SOLDERING IRON
DRIFT PIN OR TAPERED ROD
PROTECTIVE COATING COMPOUND (EPOXY RESIN OR SIMILAR COMPOUND)
APPLY HEAT TO SOFTEN COMPOUND
CHASSIS HOLDING JIG (SEE EIB #553)
BE SURE COLLAR OF TRANSITOR IS ON THIS SIDE BEFORE APPLYING PRESSURE
CUT LEADS
DOWEL PINS OR EQUIVALENT

70.114

Figure 16-11.—Removing a transistor that has been through-board mounted.

leads to the shape and length required for easy replacement. Use sharp cutters, and do not place undue stress on any lead entering the transistor. The leads are fragile, and are therefore susceptible to breaking by excessive bending or too sharp a bend. Shape any bend required in a gradual curve, at least 1/4 inch to 3/8 inch from the base of the transistor. A safety measure which can be taken to ensure that the lead will not break off at the base is to use two pairs of needle-nose pliers. With one pair grasp the lead close to the transistor base, while shaping the rest of the lead with the other pair.

After the remaining pieces of the defective transistor-terminal leads have been removed and the terminals on the board cleaned and prepared, connect the new transistor to its proper terminals.

SYSTEM TROUBLESHOOTING AIDS

Basically, the purpose of corrective maintenance is to restore the system's operation to acceptable standards. To restore the system to its operational standard, the operation and the standards of the system must be known. Firsthand knowledge of the system's operation can be obtained by performing the tests and the preventive maintenance. The system's OPs contain detailed information on the system's operation, as well as the functions of the major units in the system. Some of the maintenance oriented diagrams supplied to assist you in troubleshooting the weapon system as a unit are discussed in this chapter.

One-Function Schematic Diagram

The drawings show the internal and interconnecting circuitry between all parts of the weapon system. They depict, in a single diagram, all of the circuits involved in one particular function (quantity or signal) of a system. This eliminates the need for using many separate diagrams for each of the equipments involved in the particular function. Circuit information is displayed by functional flow from left to right. The unit in which the signal originates is on the left of the drawing, the unit that ultimately receives the signal is to the right. All major pieces of equipment, terminal boards, patch panels, indicators, plugs, and other electrical components are labeled.

These one-function diagrams are not only an aid in troubleshooting, but they provide a key to the understanding of the entire weapon system.

Data Functional Diagrams

These diagrams show data transmission and functional circuits relevant to a weapon system's loops or modes of operation. Primary data flow is depicted as heavy lines. Each diagram emphasizes all alternate and test inputs and all points of data readout such as servodials, test points, and scope indications for a particular loop or mode. By tracing the primary data flow lines you can quickly determine which components are significant to fault isolation and functional understanding.

Control Functional Diagrams

These diagrams are provided only for the more complex control circuits. The diagrams show the time related, ON-OFF stages of lamps, relays, switches, and other control devices for the various control circuits, with primary data flow depicted as heavy lines. Use of these diagrams should enable you to quickly determine the desired ON-OFF stage of the various control or control-related devices. A comparison with the actual circuit indications should isolate a fault to specific functional areas or to components in the control circuit.

EQUIPMENT TROUBLESHOOTING AIDS

Servicing Block Diagrams

This troubleshooting aid should enable the technician to see, in a general way, the course of each circuit. From it you can perceive the relationship between circuits and components. Also, you can determine the general location of the test points for checking the condition of the equipment. The servicing block diagram should aid you in localizing the trouble to a small segment of the equipment.

Schematic Diagrams

A schematic diagram shows how the parts of a circuit are connected for the operation of the equipment. It does not tell how the parts look, or how they are constructed. Each component is illustrated by a symbol. A set of schematics enables the technician to trace the passage of energy throughout the entire equipment. The detail of each circuit is drawn. This enables the technician to determine, by test, the operating condition of each part and connection.

Voltage Distribution Diagrams

These diagrams trace the distribution of the supply voltages throughout the equipment. The diagrams show all the relays, contacts, switches, and access points for that particular voltage distribution.

Voltage and Resistance Charts

These charts show the normal voltage and resistance values at the pins of connectors and tube sockets. Voltage and resistance charts are used to pinpoint the faulty element after it has been isolated through the use of troubleshooting charts and servicing diagrams. After isolating the source of trouble to a stage or area of a circuit, determine which chart you should use. Generally, there is one for each chassis in the equipment. Using servicing diagrams for reference, check the voltage in the circuit starting with the input stage and continuing until the output is reached. Repeat this procedure for resistance measurements. When an abnormal indication is observed, discontinue the procedure and check the component or components involved to pinpoint the trouble. However, keep in mind that various controls will affect voltage and resistance readings; if a faulty reading is obtained, these controls should be checked for their proper setting.

Equipment Troubleshooting Pyramids

These pyramids deal with the interdependency of the subassemblies essential to each function of a piece of equipment. The pyramid starts with an output function and, for a given local test setup, lists the values and allowable tolerances of that function. Subsequent checks of the various inputs that affect the function are contained in blocks which radiate downward from the statement of the function. The blocks contain recommended corrective action if the check of the input is at fault. Each leg of the pyramid is terminated by an input and reference to other pyramids or related documents, or by a source assembly such as an oscillator. Thus, the equipment troubleshooting pyramids should enable you to quickly localize faults and to perform the necessary corrective action by referencing the associated material.

SAFETY PRECAUTIONS

Much has been written on the subject of safety precautions. Consequently, the number of accidents which occur in the Navy is small. Most of the safety precautions applicable to fire control technicians are published in the OPs on the weapon system and on fire control equipment. It is up to you to familiarize yourself thoroughly with these safety precautions. Many of the safety regulations included in these OPs are the result of actual experience, so give them every possible consideration.

Although many specific safety precautions are laid down in the OPs, there are a few general precautions which you should remember. Let's start by discussing the handling of handtools and power tools.

HANDLING TOOLS AND MACHINERY

Many accidents occur because of the improper handling of tools. In general, these accidents occur in the form of physical injury to the person operating the tools. The following list gives the more important general precautions to follow:

1. Whenever chipping, buffing, or grinding with handtools and power tools, always wear goggles to protect the eyes. Little chips from a spinning grind wheel, or a bristle from a revolving wire brush can easily put out an eye.

Many of these machines are provided with a guard: be sure to use it.

2. Always ground the provided ground lead located at the plug of portable tools (such as electric drills) to protect yourself from shock in case a ground occurs within the tool.

3. When working with sharp handtools, always work so that the tool is moved or thrust away from the body.

4. Never wear loose clothing or a neckerchief when working with rotating tools or machinery. Such clothing may become caught in the spinning parts and drag you bodily into the machine, causing severe physical injury.

5. Never use metal handtools on energized electrical equipment or circuits because you may get shocked, or the tool may cause a short circuit causing molten copper to be blown into your face and eyes.

6. Never use handtools around running machinery, nor perform adjustments to running machinery unless absolutely necessary.

7. Never lay handtools on top of running machinery where vibration may cause the tool to fall into exposed working parts.

8. In the event it is necessary to work on electric equipment while in an energized state, wear rubber gloves, use tools with insulated handles, and stand on an insulated mat. Always work with one hand in order to prevent the possibility of a circuit through your body from arm to arm.

9. When working with tools, always work in a physically comfortable position, and keep the weight of your body well centered.

ELECTRICAL WORK

The following list contains additional precautions and is applicable to all electrical work. This list will help you prevent electric shock or burns during daily work.

1. Do not block the high voltage protective cutout switch on doors or covers in order to keep the circuit energized with the cover off. It is intended that work be performed on such electrical equipment while the circuit is deenergized.

2. Always ground the provided ground lead located at the plug of portable tools (such as electric drills) to protect yourself from shock in case a ground occurs within the tool.

3. Always be sure that all condensers are fully discharged before commencing work on a deenergized high voltage circuit. Use an insulated shorting bar for this purpose.

4. Tag the switch OPEN at the switchboard supplying power to the circuit on which you wish to work. (To properly tag a switch open, the tag must be logged in, serialized, and signed by proper authorization. Strict procedures are adhered to in order to maintain your safety.) When possible, remove the fuses protecting the circuit and place them in your tool box for safekeeping until the job is complete.

5. Always remove fuses with fuse pliers, and never remove fuses until after opening the switch connecting the circuit to the source of supply. Never replace a fuse with one LARGER than the circuit is designed to take.

6. Never use an incandescent test lamp unless its voltage rating is greater than the highest voltage which may be tested.

7. Always test a supposedly deenergized circuit with a voltage tester before commencing work on the circuit.

8. Never work on an electric circuit or network without first thoroughly acquainting yourself with its arrangement and with its points of power feed.

SAFETY FEATURES IN ELECTRONIC EQUIPMENT

You should be aware of the safety features that are generally included in electronic equipment. Some of the common safety features are interlock switches, bleeder resistors, current-limiting resistors, insulating controls, and powerline safety devices such as fuses. Keep in mind that these features cannot always be counted on to function. Do not develop a false sense of security just because the equipment has safety features.

PRECAUTIONS WHEN HANDLING ELECTRON TUBES

The use of high-powered and special purpose electron tubes in radar and microwave equipment presently being used in conjunction with digital computing equipment makes it necessary for the FT to have a thorough knowledge of the operation and dangers involved when working with these tubes.

Cathode-Ray Tubes

Cathode-ray tubes should always be handled with extreme caution. The glass envelope encloses a high vacuum and, because of its large surface area, is subject to considerable force caused by atmospheric pressure. (The total force on the surface of a 10-inch crt is 3,750 pounds, or nearly 2 tons; over 1,000 pounds is exerted on its face alone.) Proper handling and disposal instructions for a crt are as follows:

1. Avoid scratching or striking the surface.
2. Do not use excessive force when removing or replacing the crt in its deflection yoke or its socket.
3. Do not try to remove an electromagnetic crt from its yoke until the high voltage has been discharged from its anode connector (hole).
4. Never hold the crt by its neck.
5. Always set a crt with its face down on a thick piece of felt, rubber, or smooth cloth.
6. Always handle the crt gently. Rough handling or a sharp blow on the service bench can displace the electrodes within the tube, causing faulty operation.
7. Safety glasses and gloves should be worn when handling a crt.

Radioactive Electron Tubes

Electron tubes containing radioactive material are now commonly used. These tubes are known as transmit-receive (TR), antitransmit-receive (atr), spark-gap, voltage-regulator, gas-switching, and cold-cathode gas-rectifier tubes. Some of these tubes contain radioactive material and have intensity levels which are dangerous; they are so marked in accordance with ' Military Specifications.

So long as these electron tubes remain intact and are not broken, no great hazard exists. However, if these tubes are broken and the radioactive material is exposed, or escapes from the confines of the electron tube, the radioactive material becomes a potential hazard. The concentration of radioactivity in a normal collection of electron tubes in a maintenance shop does not approach a dangerous level, and the hazards of injury from exposure are slight. However, at major supply points, the storage of large quantities of radioactive electron tubes in a relatively small area may create a hazard. For this reason, personnel working with equipment employing electron tubes containing radioactive material, or in areas where a large quantity of radioactive tubes is stored, should read and become thoroughly familiar with the safety practices contained in Radiation, Health, and Protection Manual, NAVMED P-5055. Strict compliance with the prescribed safety precautions and procedures of this manual will help to avoid preventable accidents, and to maintain a work environment which is conducive to good health.

The following precautions should be taken to ensure proper handling of radioactive electron tubes and safety of personnel:

1. Radioactive tubes should not be removed from cartons until immediately prior to actual installation.
2. When a tube containing a radioactive material is removed from equipment, it should be placed in an appropriate carton to prevent possible breakage.
3. A radioactive tube should never be carried in your pocket, or elsewhere on your person in such a manner that breakage can occur.
4. If breakage does occur during handling or removing of a radioactive electron tube, notify the cognizant authority and obtain the services of qualified radiological personnel immediately.
5. Isolate the immediate area of exposure to protect other personnel from possible contamination and exposure.
6. Follow the established procedures set forth in NAVMED P-5055.
7. Do not permit contaminated material to come in contact with any part of the body.
8. Take care to avoid breathing any vapor or dust which may be released by tube breakage.
9. Wear rubber or plastic gloves at all times during cleanup and decontamination procedures.

10. Use forceps for the removal of large fragments of a broken radioactive tube. The remaining small particles can be removed with a vacuum cleaner, using an approved disposal collection bag. If a vacuum cleaner is not available, use a wet cloth to wipe the affected area. In this case, be sure to make one stroke at a time. DO NOT use a back-and-forth motion. After each stroke, fold the cloth in half, always holding one clean side and using the other for the new stroke. (Dispose of the cloth in the manner stated in item 14.)

11. No food or drink is to be brought into the contaminated area or near any radioactive material.

12. Immediately after leaving a contaminated area, personnel who have handled radioactive material in any way are to remove any clothing found to be contaminated. They must also thoroughly wash their hands and arms with soap and water, and rinse with clean water.

13. Immediately notify a medical officer if a wound is sustained from a sharp radioactive object. If a medical officer cannot reach the scene immediately, mild bleeding should be stimulated by pressure about the wound and the use of suction bulbs. DO NOT USE THE MOUTH. If the wound is of the puncture type, or the opening is small, make an incision to promote free bleeding, and to facilitate cleaning and flushing of the wound.

14. When cleaning a contaminated area, you should seal all debris, cleaning cloths, and collection bags in a container such as a plastic bag, heavy wax paper, or glass jar, and place in a steel can until disposed of in accordance with existing instructions. Decontaminate all tools and implements used to remove a radioactive substance, using soap and water. Monitor the tools and implements for radiation with an authorized radiac set; they should emit less than 0.1 MR/HR at the surface.

OPERATING FIRE CONTROL EQUIPMENT

It is imperative that you become thoroughly familiar with the safety regulations provided in the OPs and with those regulations posted aboard ship, before operating fire control equipment. You will be taught how to apply many of these precautions while you are learning to operate fire control instruments. The following list of general precautions will assist you.

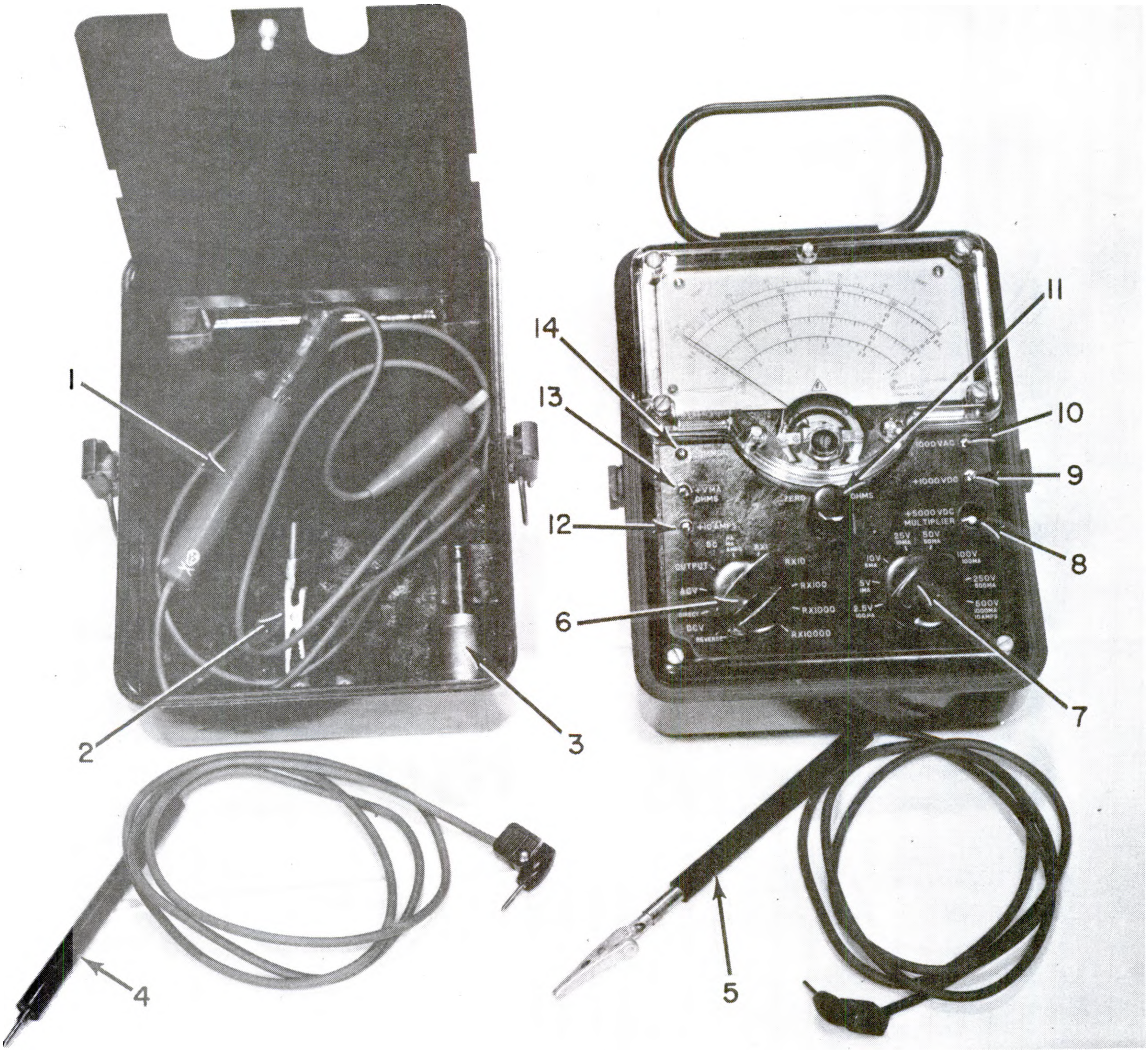
1. Always inspect all training and elevating areas to make certain that all persons are clear, and that the areas are free of obstructions before operating directors, guns, or missile launchers.
2. Always use warning bells before training or elevating gun mounts or launchers during routine work and practices.
3. Before leaving directors, guns, or launchers, always train and elevate them to their securing positions; place all controls in the inoperative position, and deenergize all power supplied to them.
4. Slew directors and guns only when it is necessary during practices.
5. All telephone stations should be manned when operating systems automatically or remotely.
6. Notify all operators and persons concerned before shifting a system to automatic control from local control.
7. Never operate directors or guns in automatic without having the regular operators posted at their stations.
8. Do not hesitate to stop personnel from operating fire control equipment if they may cause harm to themself, the equipment, or to any other person.

GENERAL PURPOSE TEST EQUIPMENT

This topic covers some of the general purpose electrical and electronic test equipment and their use in the maintenance of fire control equipment. The theory of general purpose test equipment is covered in the *NEETS Module 16, Introduction to Test Equipment.* Therefore, this chapter concentrates on the operation of test equipment and the techniques of their use. You will find that there are various instruments that perform the same functions, so, a representative instrument has been selected for each type of general purpose test equipment discussed here.

MULTIMETER

The multimeter (fig. 16-12) is designed to permit the measurement of voltage, resistance, and current with a completely self-contained portable instrument. It can measure either a.c. or d.c. voltage, d.c. resistance, or direct current in a wide range of values. This capability covers the basic requirements for a portable tester of this type. All leads and accessories are stored in



1. High-voltage probe
2. Alligator clips
3. Telephone plug
4. Standard test lead (red)
5. Standard test lead (black)
6. Function switch
7. Current and voltage range selector
8. +5,000 volts d.c. multiplier
9. +1,000 volts d.c. (red lead)
10. 1,000 volts a.c. (red lead)
11. Zero ohms
12. +10 amps (red lead
13. +Volts/MA/ohms (red lead)
14. Common (black lead)

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Figure 16-12.–Multimeter.

an accessory compartment built into the cover, which should remain with the instrument at all times. The cover forms a watertight seal when clamped over the face of the meter. While the instrument is in use, the cover clamps over the back of the meter keeping the accessory compartment convenient to the operator. Batteries are used with the multimeter, which make it extremely portable, especially in hard to get at places aboard ship.

The accessory compartment contains a pair of standard test leads (one read and one black) which are used for most applications of the instrument. These leads have elbow probes on one end to connect the lead into the circuit jacks on the instrument. They have probe tips on the other end, which have threaded shoulders to accept the alligator clips (which are screwed on). These parts are used to make all measurements, except d.c. voltages over 1,000 volts.

For measuring d.c. voltages over 1,000 volts, a special high-voltage probe is provided, and is used in conjunction with the standard black lead. One end of the lead has a threaded tip which screws on a post in the face of the meter (labeled 5,000 VDC MULTIPLIER). The other end of the lead has a high-voltage multiplier assembly made of red plastic with a clear plastic end and terminates in an alligator clip at the end of a short piece of flexible wire. The clear plastic end allows the operator to observe the glow of a neon lamp when there is high voltage present. This is a warning to the operator that there is high voltage present at the clip and that it should not be touched. The neon lamp is in series with a 100-megohm resistor within the housing. When a high voltage is being measured, the current passes through the lamp making it glow, through the resistor, and through the armature of the meter.

There are three controls on the face of the meter. One is a 10-position rotary switch in the lower left-hand corner which is used as a function switch. Five of the positions on this switch are used to set up different resistance scales. Two of the positions are for selection of d.c. voltage measurement (direct and reverse). The normal position of the switch is in the DIRECT position. If a negative voltage is to be measured, the switch is moved to the REVERSE position. (NOTE: Never switch leads to read a reverse or negative voltage.) One position of the switch is marked ACV; in this position the meter may be used to read a.c. voltage. A rectifier in the instrument changes the a.c. voltage to an equivalent d.c. value which is applied to the meter. One position is marked OUTPUT; in this position the a.c. portion of mixed a.c. and d.c. voltage may be read. The last position of the switch is used when measuring direct current and is marked DC with three ranges (μA, MA, AMPS) indicated to the right of the letters DC. In the lower right-hand corner is an eight-position switch used to select current and voltage ranges. Near the center of the meter is a control marked ZERO OHMS. This control, which is a continuously variable adjustment, is used to zero the meter, thus compensating for battery aging in the ohmmeter circuits. This control is adjusted until the meter indicates full-scale deflection (indicating zero ohms) when the function switch is set at one of the resistance range positions and the meter probes are shorted together. To prevent erroneous readings when switching to a different position, a check of the meter zero indication is always necessary.

The multimeter is designed to make the following electrical measurements:

1. Measure direct current up to 10 amperes
2. Measure resistances up to 300 megohms
3. Measure d.c. voltages up to 5,000 volts
4. Measure a.c. voltages up to 1,000 volts
5. Measure output voltages up to 500 volts

Input impedance for measuring d.c. voltages is 20,000 ohms per volt and is accurate to within 3 percent of full scale (4 percent for the 5,000 VDC scale). When measuring a.c. voltages, the input impedance is 1,000 ohms per volt and is accurate to within 5 percent of full scale.

VACUUM TUBE VOLTMETER (VTVM)

The vtvm (many versions now use solid-state circuitry) is a portable, combination electronic instrument used for general servicing of electronic equipment. It is designed for use where precise voltage, current, and resistance measurements are required. It provides a direct reading of values on a single indicating meter mounted on the control panel (fig. 16-13).

The vtvm is used primarily for the same purpose as the multimeter. Some characteristics of its operation, however, give it definite advantages over the multimeter. In the vtvm, the current and resistance measuring circuits function in a manner similar to the multimeter. The measurement of voltage, however, involves the use of an amplifier, which greatly increases the input impedance of the meter and reduces the loading effect on the circuit under test. (Less loading permits more accurate meter readings.)

Another advantage of the vtvm is its ability to accurately measure voltages at higher frequencies. Voltages at frequencies up to 50 megahertz, and sometimes even higher, can be measured accurately with this type of meter. A multimeter is accurate only in the audio-frequency range. This is because of the shunting effect across the meter's rectifier, which is due to a relatively large capacitance at higher frequencies. In the vtvm, the a.c. is not rectified in the meter's circuit, but in a special test probe.

The vtvm in figure 16-13 can measure the following:

1. a.c. volts: 0.01 to 300 in rms values
2. d.c. volts: 0.02 to 1,000
3. d.c. current: 20 microamperes to 1,000 milliamperes
4. resistance: 0.2 ohm to 1,000 megohms

When a.c. voltages are measured, the signal is first rectified by a diode in the a.c. test probe. The signal must be rectified because the meter circuit is sensitive only to d.c. voltages. When d.c. voltages are measured, the a.c. probe containing the diode rectifier is not needed.

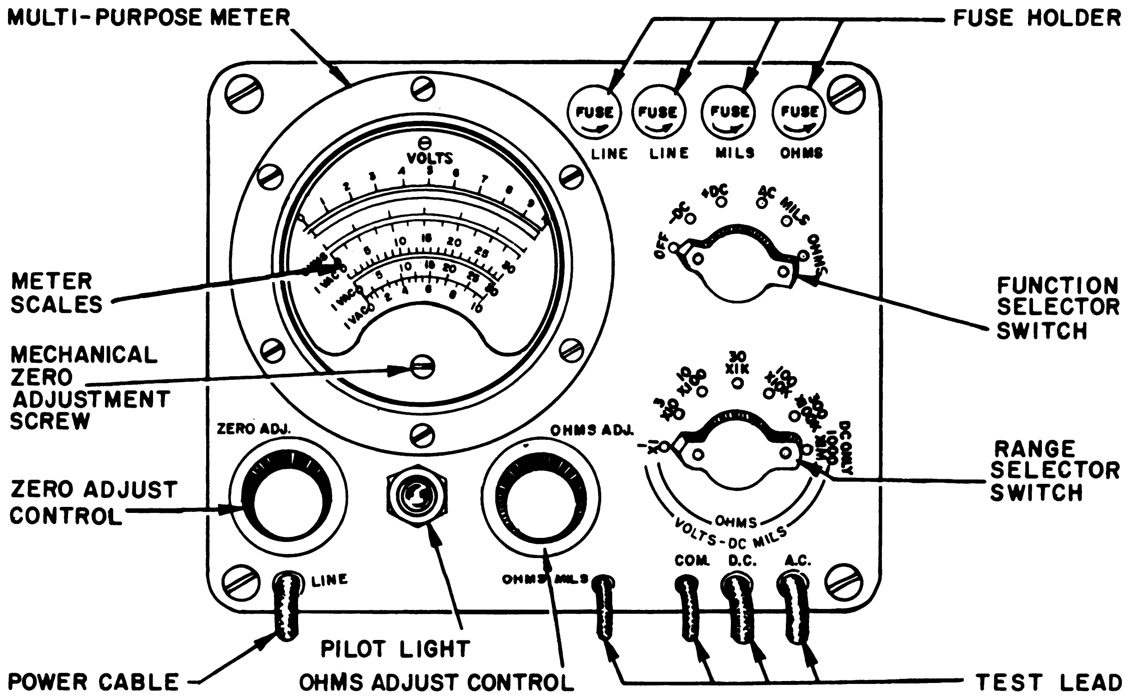

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Figure 16-13.—Electronic multimeter.

The a.c. or d.c. voltage to be measured is applied across a voltage divider network so that the total input impedance of the vtvm remains constant when the position of the range switch is changed for various levels of input voltage.

The meter is connected across a balanced bridge network. With no input, the bridge circuit is balanced and the meter reads zero. When the bridge is unbalanced by an input voltage, the meter pointer is deflected up-scale. The range switch is used to connect the necessary resistance into the circuit for each range. The resistance across the voltage divider networks reduces the input signal to a level suitable for application to the bridge. There are three voltage divider networks, one for each function, volts, ohms, and mils (milliamperes).

The ohmmeter section also utilizes the bridge circuit. When an unknown resistance is placed between the OHMS-MILS lead and the COM (common) lead, a bias voltage to the amplifier decreases in proportion to the unknown resistance. The value of the unknown resistance determines the degree to which the bridge is unbalanced and hence the magnitude of the meter pointer deflection. No battery supply is required for the ohmmeter circuitry.

The milliammeter function does not make use of the bridge circuit. The range switch connects various shunts across the meter to increase the range of current measurement.

A.C./D.C. DIFFERENTIAL VOLTMETER

The a.c./d.c. differential voltmeter is capable of being used as a conventional vtvm or as a precision potentiometer. It can also be used to measure the excursions of a voltage about some nominal value. One feature of a differential voltmeter is that no current is drawn from the unknown source for d.c. measurements when balance is attained. Thus, the determination of the unknown d.c. potential is independent of its source resistance.

An unknown voltage is measured in this type of voltmeter by comparing the unknown voltage to a known adjustable reference voltage with the aid of a built-in null detector. An accurate standard for measurement is obtained by setting the reference power supply with a standard battery cell or zener reference diode. The known adjustable reference voltage is provided by a high-voltage d.c. power supply and decade resistor strings that are set accurately by voltage readout dials. In this way, the output from the high-voltage power supply can be precisely divided into increments as small as 10 microvolts. The unknown voltage is then simply read from the voltage dials.

When used as an a.c. differential voltmeter, the a.c. input voltage is converted to a d.c. voltage and measured in the same manner as an unknown d.c. voltage.

One example of an a.c./d.c. differential voltmeter which is commonly used is shown in figure 16-14.

This instrument is a solid-state differential voltmeter which provides nonloading d.c. voltage measurements of ±10 microvolts to ±1,100 volts. With this instrument, a.c. voltages of 0.001 to 1,100 volts may be measured over a frequency range of 5 hertz to 100 kilohertz. It has four voltage readout dials which vary the resistance of the divider assembly as previously described.

MEGGERS

A Megger is an instrument that applies a high voltage to the component under test and measures the current leakage of the insulation. Thus, a capacitor or insulated cable can be checked for leakage under much higher voltages than an ohmmeter is capable of supplying. A Megger consists of a hand-driven, d.c. generator and an indicating meter. The name Megger is derived from the fact that it measures resistances of many megohms.

The Megger illustrated in figure 16-15 is designed to measure insulation resistance from 0 to 1,000 megohms. The testing voltage is 500 volts d.c.

The meter pointer should read infinite resistance when there are no external connections to the output binding posts, L and GND. If the pointer does not stand over the infinity mark, it is necessary to adjust the meter adjustment screw until the pointer does stand over the infinity mark. When the meter terminals are short-circuited and the crank is turned at normal operating speed (indicator buttons glowing steadily), the meter pointer should be over the zero mark.

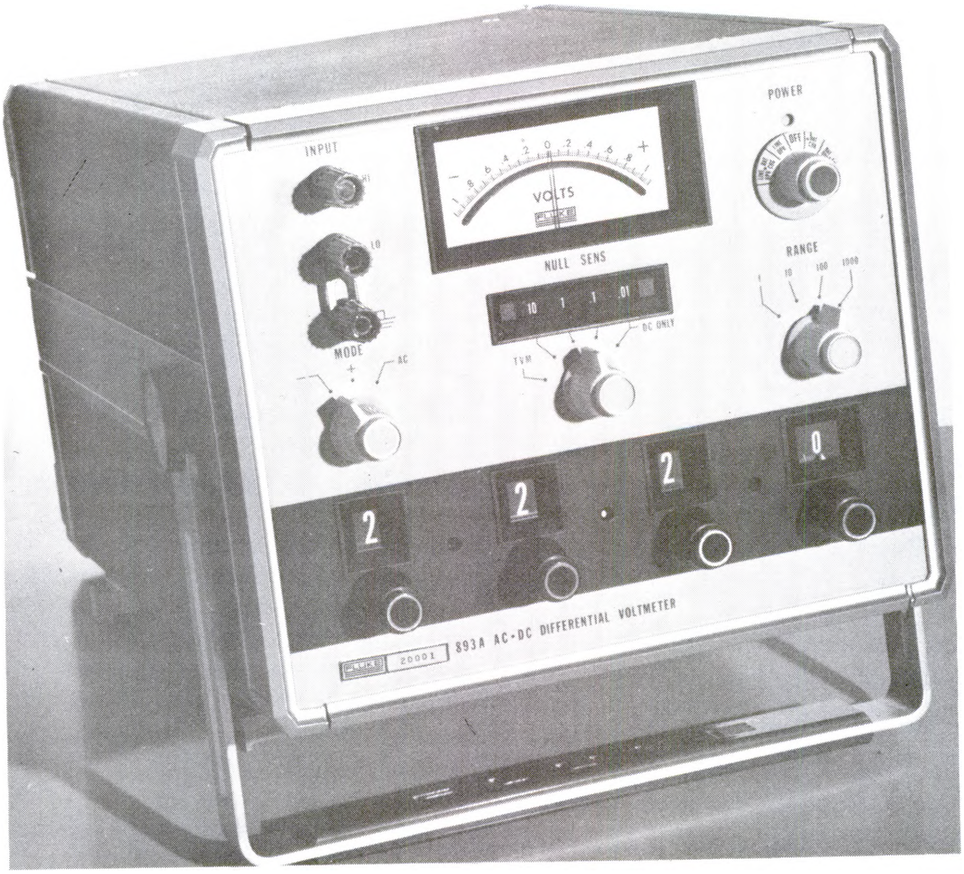

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Figure 16-14.—An a.c./d.c. differential voltmeter.

The operation of the insulation test set is relatively simple.

1. Be sure that the apparatus, line, or circuit to be tested is disconnected from its power supply in accordance with safety instructions. Ground the apparatus, line, or circuit to be tested to discharge any capacitors connected to it.

2. Connect the spade terminal lug of the black lead to the GND binding post of the test set.

3. Attach the alligator clip of the black test lead to the side of the circuit (under test) nearest ground potential.

4. Connect the spade terminal lug of the red lead to the L binding post of the test set.

5. Attach the alligator clip of the red test lead to the conductor to be tested.

6. Turn the crank in either direction at the minimum speed required to provide steady illumination of the indicator buttons.

7. Read the megohms of resistance offered by the material being tested. If the resistance is more than 1,000 megohms at 500 volts d.c., the meter will remain at rest over the infinity mark (∞), indicating that the resistance of the insulation being tested is beyond the range of the meter. (Meggers should not be used on some equipment; when in doubt, check the equipment OP.)

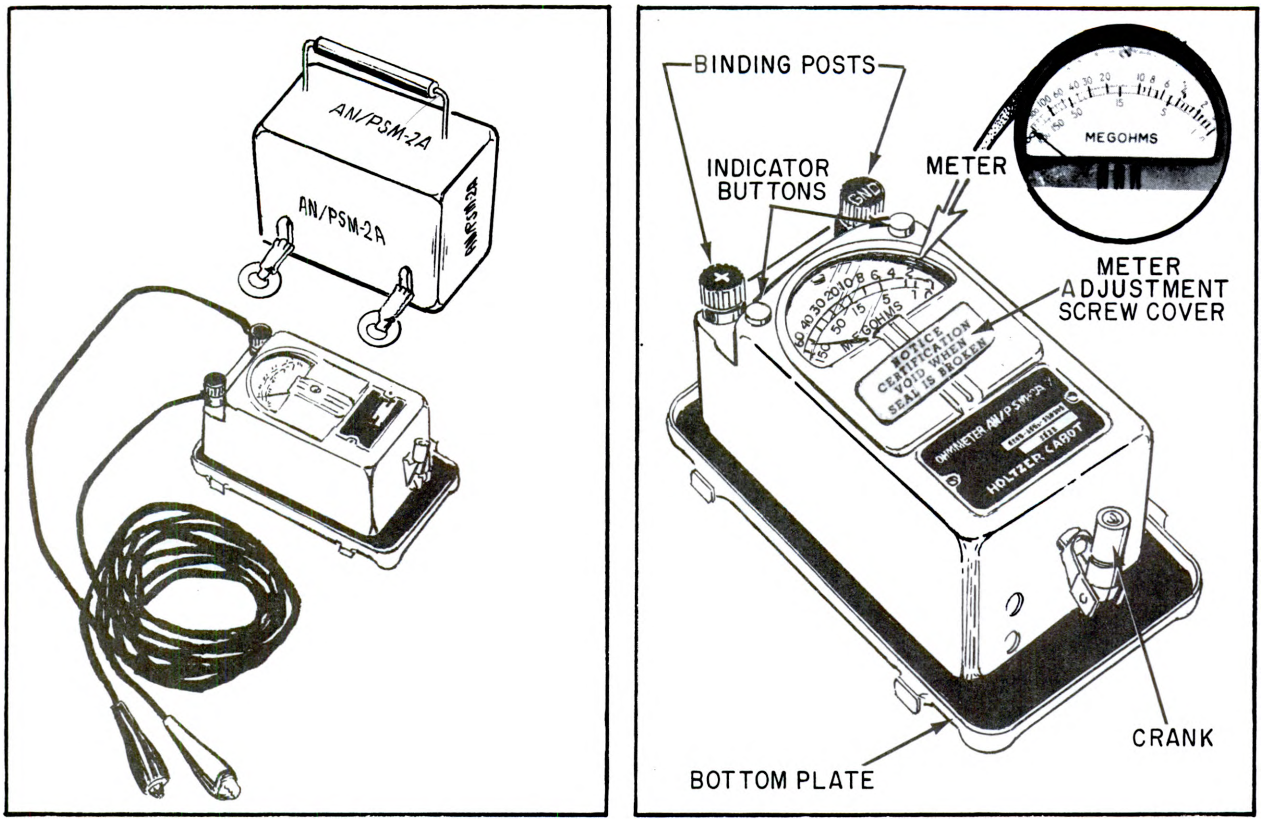

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Figure 16-15.—Insulation test set (Megger).

TECHNIQUES FOR METER USE

The meters discussed thus far in this chapter are among the most commonly used varieties. They are employed in a number of ways, some of which are discussed in the following sections of this chapter. The techniques suggested here are not all-inclusive. You will find, as you develop your technical skill, there are other variations and techniques in use. As an example, consider the techniques for measuring current in a circuit. This can be done by placing an ammeter in series. It can also be accomplished by measuring the voltage across a resistor of known value. Then, by application of Ohm's law, the current in the circuit can be calculated. This last technique has the advantage of eliminating the necessity of opening the circuit for placement of the ammeter.

Continuity Test

Open circuits are those in which the flow of current is interrupted by a broken wire, a defective switch, or any means by which the current cannot flow. The test used to check for opens (or to see if the circuit is complete or continuous) is called CONTINUITY TESTING.

An ohmmeter (which contains its own batteries) is excellent for a continuity test. In an emergency, a continuity test can readily be made using two sound-powered telephone handsets. Normally, continuity tests are performed in circuits where the resistance is very low (such as the resistance of a copper conductor). An open is indicated in these circuits by a very high or infinite resistance.

The diagram in figure 16-16 shows a continuity test of a cable connecting two fire

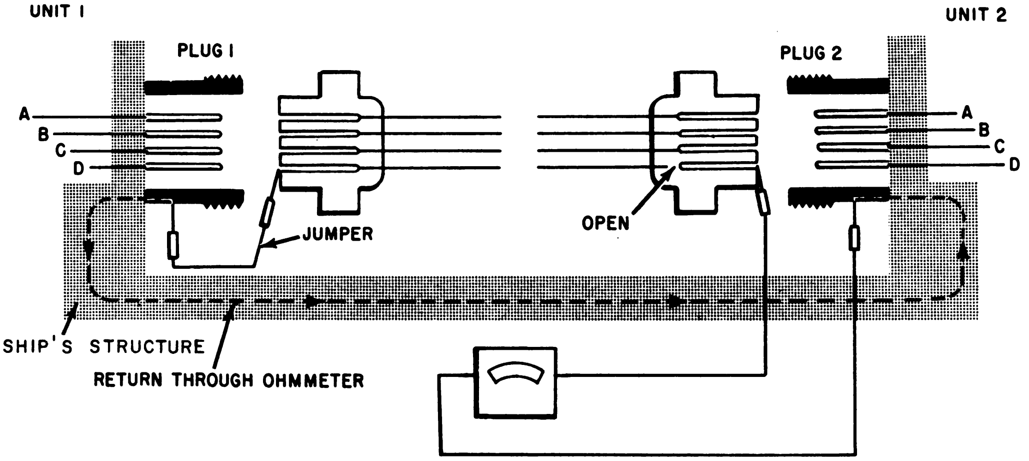

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Figure 16-16.—Continuity test.

control units. Notice that both connectors are disconnected and the ohmmeter is in series with the conductor under test. The power should be off. Checking conductors A, B, and C, the current from the ohmmeter flows through plug No. 2, through the conductor, and through plug No. 1. From this plug, it passes through the jumper to the chassis, which is "grounded" to the ship's structure. The metal structure serves as the return path to the chassis of unit 2, completing the circuit to the ohmmeter. The ohmmeter then indicates a low resistance.

Checking conductor D in figure 16-16 an open is revealed. The ohmmeter indicates maximum resistance because current cannot flow. With an open circuit, the ohmmeter needle is all the way to the left, since it is a series type of ohmmeter (reads right to left).

Where conditions are such that the ship's structure cannot be used as the return path, one of the other conductors may be used. For example (referring to fig. 16-16), to check D, a jumper is connected from pin D to pin A of plug 1 and the ohmmeter leads are connected to pins D and A of plug 2. This technique also reveals the open in the circuit.

Test for Grounds

Grounded circuits are caused by some conducting part of the circuit making contact either directly or indirectly with the metallic structure of the ship. Grounds may have many causes. The two most common causes are the fraying of insulation from a wire, allowing the bare wire to come in contact with the metal ground, and moisture-soaked insulation.

Grounds are usually indicated by blown fuses or tripped circuit breakers. Blown fuses or tripped circuit breakers, however, may also result from a short other than a ground. A high-resistance ground may also occur where not enough current can flow to rupture the fuse or open the circuit breaker.

In testing for grounds, you may use a Megger or an ohmmeter. By measuring the resistance to ground of any point in a circuit, you can determine if the point is grounded. One possible means of testing a cable for grounds can be seen in figure 16-16. If the jumper is removed from pin D of plug 1, a test for grounds is made for each conductor of the cable. This is accomplished by connecting one meter lead to ground and the other individually to each of the pins of one of the plugs. A low resistance for any one pin indicates that pin is grounded. Both plugs must be removed from their units; if only one plug is removed, a false indication is possible, for a conductor may be grounded through the unit.

Test for Shorts

A short circuit, other than a grounded one, is one where two conductors accidentally touch each other directly or through another conducting element. Two conductors with frayed insulation may touch and cause a short. Too much solder on the pin of a connector may short to the adjacent pin. In a short circuit, enough current may flow to blow a fuse or open a circuit breaker. However, it is entirely possible to have a short between two cables carrying signals; such a short will not be indicated by a blown fuse.

For continuity checks, the device used for checking for a short is the ohmmeter. By measuring the resistance between two conductors, a short between them may be detected by a low resistance reading. In figure 16-16, by removing the jumper and disconnecting both plugs, a short test may be made. This is performed by measuring the resistance between the two suspected conductors.

Shorts occur in many components, such as transformers, motor windings, capacitors, and the like. The major test method for detecting such components is taking a resistance measurement, and then comparing the indicated resistance with the resistance given on schematics or in the equipment OP.

Voltage Test

The voltage test must be made with the power applied; therefore, the prescribed safety precautions MUST be followed to prevent injury to personnel and damage to the equipment. You will find in your maintenance work that the voltage test is of utmost importance. It is used not only in isolating casualties to major components, but also in the maintenance of subassemblies, units, and circuits. Before checking a circuit voltage, a check on the voltage of the power source is made to be sure that the normal voltage is being impressed across the circuit.

Obviously, the voltmeter is used for voltage tests. In using the voltmeter, make certain that the meter used is designated for the type of current (a.c. or d.c.) to be tested and has a scale of adequate range. Since defective parts in a circuit may cause higher than normal voltages to be present at the point of test, the highest voltmeter range available should be used at first. Once a reading has been obtained, determine if a lower scale can be employed without damaging the meter movement. If so, use the lower scale, to obtain a more accurate reading.

Another consideration in the circuit voltage test is the resistance and current in the circuit. A low resistance in a high-current circuit would result in considerable voltage drop, whereas the same resistance in a low-current circuit might be negligible. Abnormal resistance in part of a circuit can be checked with either an ohmmeter or a voltmeter. Where practical, an ohmmeter should be used, because the test is then carried out with the circuit "dead."

The majority of the electronics circuits encountered in fire control equipment are low-current circuits, and most voltage readings are direct current. Also, many of the schematics indicate the voltages at many test points. Thus, if a certain stage is suspected and a voltage check is desired, a voltmeter placed from the test point to ground should read the voltages as given on the schematic.

Some OPs also contain voltage charts where all the voltage measurements are tabulated. These charts usually indicate the sensitivity of the meter used to obtain the voltage readings for the chart. To obtain comparable results, a voltmeter of the same sensitivity as that specified must be used. Make certain that the voltmeter is not loading the circuit while taking a measurement. If the meter resistance is not considerably higher than the circuit resistance, the reading will be markedly lower than the true circuit voltage. (To calculate the meter resistance, multiply the rated ohms-per-volt sensitivity value of the meter by the scale in use. For example, a 1,000 ohms-per-voltmeter set to the 300-volt scale has a resistance of 300,000 ohms.)

Resistance Test

Before checking the resistance of a circuit or of a part, make certain that the power has been turned off and that the capacitors in the associated circuit are discharged. To check continuity, always employ the lower ohmmeter range. If a high range is used, the meter may indicate zero even though appreciable resistance is present in the circuit. Conversely, to check a high resistance, use the highest scale, since the low-range scale may indicate infinity though the resistance is less than a megohm.

In making resistance tests, take into account that other circuits that contain resistances and capacitance may be in parallel with the circuit to be measured, in which case an erroneous conclusion may be drawn from the reading obtained. Remember, a capacitor will block the d.c. flow from the ohmmeter. To obtain an accurate reading if other parts are connected across the suspected circuit, one end of the circuit to be measured is disconnected from the equipment. For example, many of the resistors in major components and subassemblies are connected across transformer windings. To obtain a valid resistance measurement, the resistor to be measured must be isolated from the shunt resistances.

Resistance tests are also used for checking a part for grounds. In these tests, the parts should be disconnected from the rest of the circuit so that no normal circuit ground exists. It is not necessary to dismount the part to be checked. The ohmmeter, which is set for a high resistance range, is then connected between ground and each electrically separate circuit of the part under test. Any resistance reading less than infinity indicates at least a partial ground. Capacitors suspected of being short circuited can also be checked by a resistance measurement. To check a capacitor suspected of being open, temporarily shunt a known perfect capacitor across it, and recheck the performance of the circuit.

PRECAUTIONS IN USE OF METERS

The following are guides for the proper use of meters.

1. An ammeter is always connected in series—NEVER in parallel.
2. A voltmeter is connected in parallel.
3. An ohmmeter is NEVER connected to a live circuit.
4. Polarity must be observed in the use of a d.c. ammeter or a d.c. voltmeter.
5. Meters should be viewed directly from the front. When viewed from an angle off to the side, an incorrect reading results because of optical parallax.
6. Always choose an instrument suitable for the measurement desired.
7. Select the highest range FIRST, and then switch to the proper range.
8. In using a meter, choose a scale which results in an indication as near midscale as possible.
9. Do not mount or use instruments in the presence of a strong magnetic field.
10. Remember, a low internal resistance voltmeter (low sensitivity) may shunt the circuit being measured and result in incorrect readings.

ELECTRON TUBE TESTER

In electronic equipment where electron tubes are used, it has been found that these tubes cause more than 50 percent of all electronic equipment failure.

The condition of a tube can be determined by substituting a tube known to be good for the questionable one. However, indiscriminate substitution of tubes is to be avoided, as detuning of circuits may result. In addition, a tube may not operate properly in a high-frequency circuit, although it performs well in a low-frequency circuit. Therefore, if you are to service electronic equipment, a knowledge of tube-testing devices and their limitations, as well as correct interpretation of the test results obtained, is indispensable for accurate and rapid job performance.

In order to determine the condition of an electron tube, some method of testing is necessary. Because the operating capabilities (and design features) of a tube are shown by its electrical characteristics, a tube is tested by measuring its characteristics and comparing them with representative values established as standard for that type of tube. Tubes which read abnormally high or low with respect to the standard are subject to suspicion. Practical considerations, which take into account the limitations of the tube test in predicting actual tube performance in a particular circuit, make it unnecessary to employ complex and costly test equipment having laboratory accuracy. For most applications, the testing of a single tube characteristic suffices to determine whether a tube is performing satisfactorily.

Testing the emission characteristic of the cathode or filament is perhaps the simplest method of determining the condition of a tube. Since emission normally decreases as the tube ages, low emission is indicative of the end of tube serviceability. This test, however, is subject to limitations, because it tests the tube under static conditions and does not consider the actual circuit operation of the tube. Furthermore, coated cathodes or filaments may develop highly emissive spots, so that the relatively small grid area adjacent to these spots cannot control the electron stream. Under these conditions, testing the total emission may indicate the tube to be satisfactory, while in reality it is defective.

The transconductance (Gm) of a tube used in an amplifier stage is normally a more useful characteristic to measure than the emission. Transconductance is the change of plate current which results from a change in grid voltage; this characteristic therefore, indicates the ability of the tube to amplify a.c. signals. The most common military tube testers provide dynamic transconductance measurements, although some of the testers are limited to static measurements of this characteristic.

It should be kept in mind that a tube-testing device only compares the characteristics of a given tube with a standard for that particular type of tube. Since the operating conditions imposed upon a tube may vary over wide limits, it is not possible for the tube tester to evaluate a tube in terms of performance capability for all applications. Therefore, the tube tester is not considered the final authority in deciding whether or not a tube is always satisfactory. Substituting a good tube in the equipment, and observing the performance of the equipment, provide the most reliable evidence concerning the condition of the tube in question. Substitution is also the only method by which you may test many high-power tubes used for transmitter applications. Nevertheless, the tube tester plays a very important function, since in most cases it provides a quick and satisfactory check on tube serviceability.

A representative field type of electron tube tester designed to test all common low-power tubes is shown in figure 16-17. The tube test conditions (which are as close as possible to the actual tube operating conditions) are programmed on a prepunched card. The card switch (S101, fig. 16-17) automatically programs the tube test conditions when it is actuated by a card. A card compartment on the front panel of the tester provides storage for the most frequently used cards. The cover of the tester (not shown) contains the operating instructions, the brackets for storing the technical manual, the power cord, the calibration cell for checking the meter and short tests, the calibration cards, the blank cards, and a steel hand punch.

Front Panel

When a prepunched card is fully inserted into the card switch (S101), a microswitch is actuated which energizes a solenoid, causing the card switch contacts to complete the circuit. The card switch has 187 single-pole, single-throw switches arranged in 17 rows with 11 switches in each row. The card is used to push the switches closed; thus, the absence of a hole in the card is required to actuate a switch.

The meter (M301 in fig. 16-17) contains four scales. The upper scale is graduated from 0 to 100 for direct numerical readings. The three lower scales, numbered 1, 2, and 3, are read for LEAKAGE, QUALITY, and GAS, respectively. Each numbered scale includes green and red areas marked GOOD and REPLACE. Inside a shield directly in front of the meter are five neon lamps (DS301 through DS305), which indicate shorts between tube elements.

The number 2 pushbutton (MP6) is used for transconductance, emission, and other quality tests (described later). The number 3 pushbutton (MP7) is used to test for the presence of gas in the tube envelope. The number 4 pushbutton (MP8) is used for tests on dual tubes. A neon lamp (DS203) lights when pushbutton number 4 is to be used. Eleven tube test sockets are located on the panel, plus tube pin straighteners for the 7- and 9-pin minature tubes.

The power ON-OFF spring-return toggle switch (S105) turns the tester on by energizing a line relay. The pilot light (DS107) lights when this relay closes. Above the power ON-OFF switch are five fuses. Fuses F101, F201, and F202 protect circuits in the tester not protected

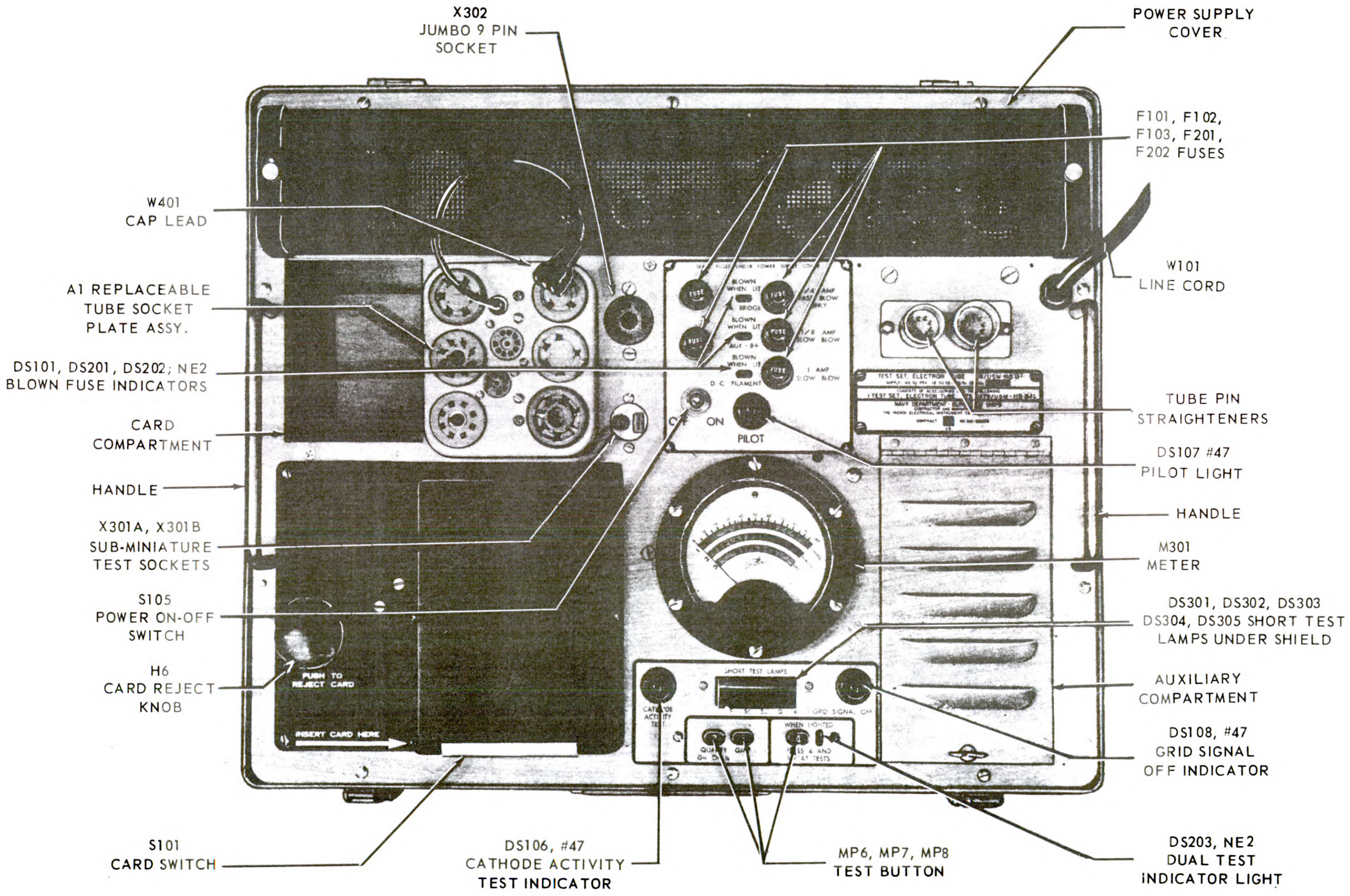

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Figure 16-17.—Electronic tube tester.

by other means and have neon lamps to indicate when they have blown. Fuses F102 and F103 protect both sides of the power line.

Auxiliary Compartment

A group of auxiliary controls covered by a hinged panel is used for special tests and for calibration of the tester. Two of these controls, labeled SIGNAL CAL (R152 and R155, fig. 16-18), are used with special test cards for adjusting the regulation and amplitude of the signal voltage. A pushbutton labeled CATH ACT (S302D) is used for making cathode activity tests. When this button is pressed, DS106 on the front panel (fig. 16-17) lights, and the filament voltage of the tube under test is reduced by 10 percent. Results of the test are read as a change in reading on the numerical meter scale.

Pushbutton S302E and potentiometers R401 and R405 (fig. 16-18) are used for balancing the Gm bridge circuit under actual tube operating current. Pressing S302E removes the grid signal and allows a zero balance to be made with one potentiometer or the other, depending upon whether the tube under test is passing high or low plate current. Lamp DS108 on the front panel lights when S302E is pressed. Pushbutton S302C is used for checking grid-to-cathode shorts at a sensitivity much higher than the normal tests. Results of this test are indicated by the short test lamps on the front panel.

Certain special tests require the use of a continuously adjustable auxiliary power supply. By pressing pushbutton S302B, meter M301 may be used to read the voltage of the auxiliary power supply. This voltage may be adjusted by the use of potentiometer R142. The rest of the potentiometer controls are calibration controls and are adjusted by the use of special calibration cards and a calibration test cell.

All circuits in the tester, except the filament supply, are electronically regulated to compensate for line voltage fluctuations. The

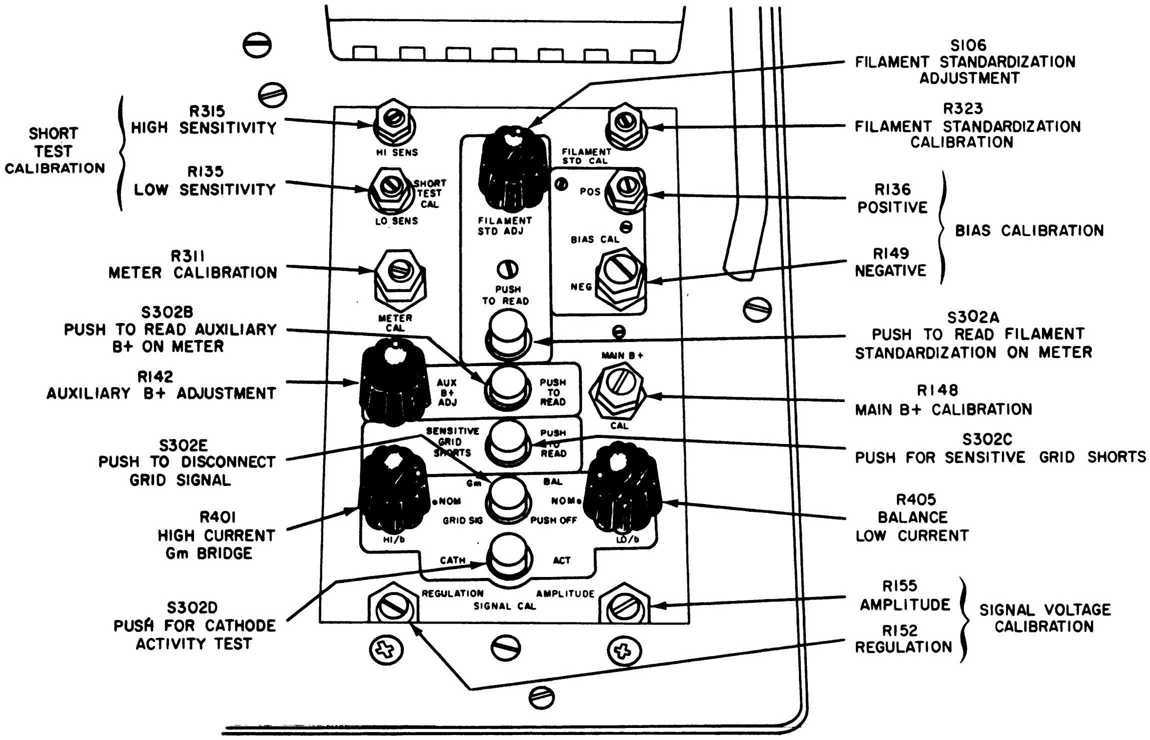

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Figure 16-18.—Auxiliary compartment.

filament supply voltage is adjusted by pressing pushbutton S302A and rotating the filament standardization adjustment switch S106 until meter M301 reads midscale.

Program Cards

As stated previously, the circuits to be used in testing are selected by a prepunched card. These cards are made of a tough vinyl plastic material. The tube numbers are printed in color on the tabs of the cards and also at the edge of the card for convenience in filing. A special card is provided to use as a marker when a card is removed for use. Blank cards are provided so that additional test cards may be punched for new tubes that are developed or to replace cards that have become unserviceable.

Operation

Before operating for the first time, and periodically thereafter, the tester should be calibrated using the calibration test cards as described in the equipment technical manual.

NORMAL TEST.–The tester is equipped with a three-conductor power cord, one wire of which is chassis ground. It should be plugged into a grounded 105- to 125-volt, 50- to 400-hertz outlet.

Before operating the tester, open the auxiliary compartment (fig. 16-18) and ensure that the FILAMENT STD ADJ and the Gm BAL knobs are in the NOM position. The GRID SIG and CATH ACT buttons (S302E and S302D) should be up and lamps DS108 and DS106 on the front panel should be out.

Turn on the tester and allow it to warm up for 5 to 10 minutes, then press the PUSH TO REJECT CARD knob (fig. 16-17) down until it locks. If a nontest card is installed in the card switch, remove it. This card is used to keep the switch pins in place during shipment and should be inserted before transporting the tester.

Plug the tube to be tested into its proper socket. (Use the pin straighteners before plugging in 7- and 9-pin miniature tubes.) Select the proper card or cards for the tube to be tested. Insert the card selected into the slot in the card switch until the PUSH TO REJECT knob pops up. The card will operate the tester only if it is fully inserted, and the printing is up and toward the operator. DO NOT put paper or objects other than program cards into the card switch, as they will jam the switch contacts. If the overload shuts off the tester when the card is inserted in the switch, check to see that the proper card is being used for the tube under test and that the tube under test has a direct interelectrode short.

As soon as the card switch is actuated, the tube under test is automatically subjected to an interelement short test and a heater-to-cathode leakage test. A blinking or steady glow of any of the short test lamps is an indication of an interelement short. If the short test lamps remain dark, no interelement shorts exist within the tube. If a short exists between two or more elements, the short test lamp or lamps connected between these elements remain dark, and the remaining lamps light. The abbreviations for the tube elements are located on the front panel just below the short test shield so that the neon lamps are between them. This enables the operator to tell which elements are shorted. Heater-to-cathode shorts are indicated as leakage currents on the #1 meter scale. If the meter reads above the green area, the tube should be replaced. A direct heater-to-cathode short causes the meter to read full scale.

To make the QUALITY test, push the number 2 button (fig. 16-17) and read the number 2 scale on meter M301 to determine if the tube is good. (This test may be one of various types, such as transconductance, emission, plate current, or voltage drop, depending upon the type of tube under test.)

To test the tube for GAS, press the number 3 button and read the number 3 meter scale. The number 2 button also goes down when number 3 is pressed. If a dual tube having two identical sections is being tested, the neon lamp (DS203) will light, indicating that both sections of the tube may be tested with one card. To do this, check the tube for shorts, leakage, quality, and gas as described previously, then hold down button number 4 and repeat these tests to test the second section of the tube. Dual tubes with sections that are not identical require two cards for testing. A second card is also provided to make special tests on certain tubes.

AUXILIARY TESTS.–As mentioned previously, two special tests (cathode activity and sensitive grid shorts) may be made by use of controls located in the auxiliary compartment (fig. 16-18). The cathode activity test (CATH ACT) is used to indicate the amount of useful life remaining in the tube. By reducing the filament voltage by 10 percent and allowing the cathode to cool off slightly, the ability of the cathode as an emitter of electrons can be estimated. This test is made in conjunction with the normal quality test.

To make the CATH ACT test, allow the tube under test to warm up, press button number 2 (fig. 16-17), and note the reading of scale number 2 on meter M301. Note also the numerical scale reading on M301. Next, lock down the CATH ACT button (fig. 16-18), wait for about 1.5 minutes, then press button number 2 (fig. 16-17) again and note the numerical and number 2 scale readings on meter M301. The tube should be replaced if the numerical reading on M301 differs from the first reading by more than 10 percent, or if the reading is in the red area on the number 2 scale.

It is sometimes desirable to check certain tubes for shorts at a sensitivity greater than normal. To make the SENSITIVE GRID SHORTS test, push S302C (fig. 16-18) and note if any short test lamps (fig. 16-17) light.

TRANSISTOR TEST SET

Laboratory transistor test sets are used in experimental work to test all characteristics of transistors. For maintenance and repair, however, it is not necessary to check all of the transistor parameters. A check of two or three performance characteristics is usually sufficient to determine whether a transistor needs to be replaced. Two of the most important parameters used for transistor testing are the transistor current gain (beta) and the collector leakage or reverse current (Ico).

The semiconductor test set (fig. 16-19) is a rugged field type of tester designed to test transistors and semiconductor diodes. The set measures the Beta of a transistor, the resistance appearing at the electrodes and the reverse current of a transistor or semiconductor diode, a shorted or open condition of a diode, the forward transconductance of a field effect transistor, and the condition of its own batteries.

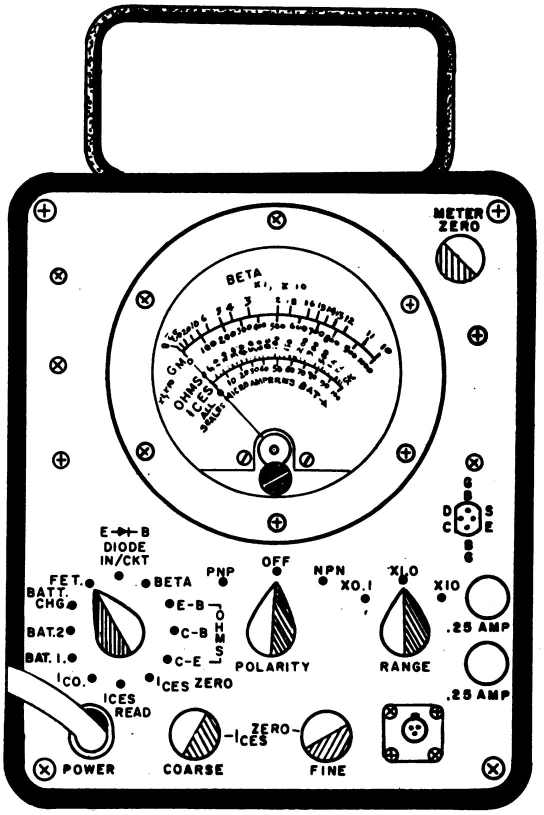

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Figure 16-19.—Semiconductor Test Set.

In order to assure that accurate and useful information is gained from the transistor tester, the following preliminary checks of the tester should be made prior to testing any transistors.

With the POLARITY switch (fig. 16-19) in the OFF position the meter pointer should indicate exactly zero. (When required, rotate the meter adjust screw on the front of the meter to fulfill this requirement.) The POLARITY switch must always be left in the OFF position, when measurements are not actually being made, to prevent battery drain.

Always check the condition of the test set batteries by disconnecting the test set power cord, placing the POLARITY switch in the PNP position, and placing the FUNCTION switch first to BAT.1 then to BAT.2. In both BAT positions the meter pointer should move so as to indicate within the red BAT range.

Beta Measurements

If the transistor is to be tested out of the circuit, plug it into the test jack located on the right-hand side below the meter shown in figure 16-19. If the transistor is to be tested in the circuit, it is imperative that at least 300 ohms exists between E-B, C-B, and C-E for accurate measurement. Initial setting of the test set controls is:

1. FUNCTION switch to BETA
2. POLARITY switch to PNP or NPN (dependent on type of transistor under test)
3. RANGE switch to X10
4. Adjust meter zero for zero meter indication (transistor disconnected)

NOTE: The POLARITY switch should remain OFF while the transistor is connected to or disconnected from the test set. If it is determined that the Beta reading is less than 10, reset the RANGE switch to X1 and reset the meter to zero.

After connecting the yellow test lead to the emitter, the green test lead to the base, and the blue test lead to the collector, plug the test probe (not shown) into the jack located at the lower right-hand corner of the test set. When testing grounded equipment, unplug the 115 VAC line cord and use battery operation. The Beta reading is attained by multiplying the meter reading times the RANGE switch setting. Refer to the transistor characteristics book provided with the tester to determine if the reading is normal for the type of transistor under test.

Electrode Resistance Measurements

Connect the in-circuit probe test leads to the transistor with the yellow lead to the emitter, the green lead to the base, and the blue lead to the collector. Set the FUNCTION switch to the OHMS E-B position, and read the resistance between the emitter and base electrode on the center scale of the meter.

To read the resistance between the collector and base and the collector and emitter, set the FUNCTION switch to OHMS C-B and OHMS C-E. These in-circuit electrode resistance measurements are used to correctly interpret the in-circuit beta measurements. The accuracy of the BETA X1, X10 range is ±15 percent only when the emitter to base load is equal to or greater than 300 ohms.

ICO Measurements

Adjust the METER ZERO control for zero meter indication. Plug the transistor to be tested into the jack or connect test leads to the device under test. Set the PNP/NPN switch to correspond with the transistor under test. Set the FUNCTION switch to ICO, and the RANGE switch to X0.1, X1, or X10 as specified by the transistor data book for allowable leakage. Read the amount of leakage on the bottom scale, and multiply this by the range setting figure as required.

Diode Measurements

Diode qualitative in-circuit measurements are attained by connecting the green test lead to the cathode and the yellow test lead to the anode. Set the FUNCTION switch to DIODE IN/CKT and the RANGE switch to X1. (Ensure that the meter has been properly zeroed on this scale.) If the meter reads down scale, reverse the POLARITY switch. If the meter reads less than midscale, the diode under test is either open or shorted. The related circuit impedance of this test is less than 25 ohms.

Precautions

Transistors, although generally more rugged mechanically than electron tubes, are susceptible to damage by excessive heat and electrical overload. The following precautions should be taken in servicing transistorized equipment.

1. Test equipment and soldering irons must be checked to make certain that there is no leakage current from the power source. If leakage current is detected, isolation transformers must be used.

2. Ohmmeter ranges which require a current of more than 1 milliampere in the test circuit are not to be used for testing transistors.

3. Battery eliminators should not be used to furnish power for transistor equipment because they have poor voltage regulation and, possibly, high ripple voltage.

4. The heat applied to a transistor, when soldered connections are required, should be kept to a minimum by using a low-wattage soldering iron and heat shunts (such as long-nose pliers) on the transistor leads.

5. All circuits should be checked for defects before a transistor is replaced.

6. The power should be removed from the equipment before replacing a transistor or other circuit part.

7. When working on equipment with closely spaced parts, conventional test probes are often the cause of accidental short circuits between adjacent terminals. Momentary short circuits, which rarely cause damage to an electron tube, may ruin a transistor. To avoid accidental shorts, a test probe can be covered with insulation for all but a very short length of the tip.

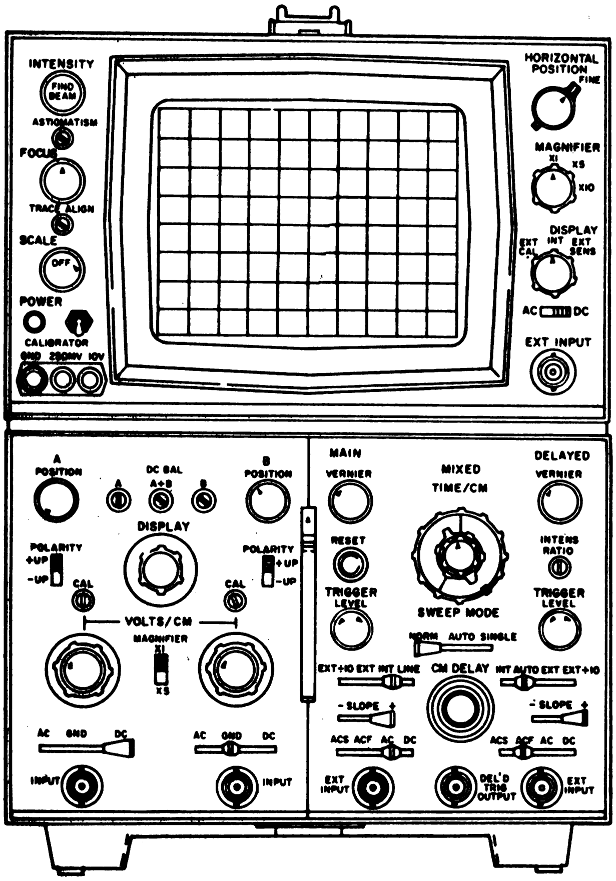

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Figure 16-20.—Oscilloscope.

OSCILLOSCOPE

The oscilloscope (fig. 16-20) is one of the most useful and versatile types of test equipment. It is essentially a device for displaying graphs of rapidly changing voltage or currents, but it is also capable of giving information concerning frequency values, phase differences, and voltage amplitude. It is used to trace signals through electronic circuits, to localize sources of distortion, and to isolate troubles to particular stages.

The voltage or current waveform is normally represented in a graphically displayed, two-dimensional (horizontal and vertical) plane with no depth involved. The horizontal ("X") axis on the oscilloscope represents either elapsed time or waveform duration in either whole or parts of a second. The vertical ("Y") axis represents amplitude, quantity, or intensity of the subject waveform in either whole or parts of volts or amperes. Any portion of the waveform extending above the present horizontal (zero amplitude) reference line is considered positive, while any portion below the horizontal reference line is considered negative (opposite to the positive portion of the subject waveform).

Most oscilloscopes consist of a major unit and any one of several plug-in units. The major unit contains the power supplies, sweep circuits, calibration circuits, cathode-ray tube (crt), and controls associated with these circuits. The plug-in units are single-channel, multichannel, or special feature preamplifiers and are selected depending on the display desired; i.e., a multichannel plug-in unit provides two separate traces on the crt and thus allows two functions (signals) to be displayed simultaneously. An instruction manual is provided with each plug-in unit, giving detailed instructions for operating that specific plug-in unit in conjunction with the oscilloscope.

The oscilloscope shown in figure 16-20 is an example of the type of oscilloscope presently in use throughout the fleet. It is a direct-coupled, wideband oscilloscope that provides a visual display of simple and complex waveforms. In addition to displaying waveforms, the oscilloscope is capable of accurately measuring the rise time of a waveform, the waveform magnitude, the time difference between any two points on a displayed waveform, and the accurate time comparison of two separate waveforms. This oscilloscope consists of essentially three operating units, the oscilloscope assembly mainframe, a dual-trace, plug-in unit (bottom left) and a time base and delay plug-in unit (bottom right).

Basic Principles of Operation

As stated earlier, the oscilloscope is a test instrument that is capable of measuring voltage, determining frequencies, and visually displaying waveforms. Some oscilloscopes can also display two waveforms at the same time, making comparisons possible. The oscilloscope is commonly referred to as an O-SCOPE or SCOPE.

Oscilloscopes vary from the simple to the complex. They are made in a number of sizes by many manufacturers. Therefore, there are many models, but they all have certain elements in common. First, all scopes have a cathode-ray tube which has a face, or screen, where waveshapes are visually displayed. Secondly, controls are provided to adjust the display so voltage, time, and frequency can be determined.

CONTROLS.–An important control, and one common to all scopes, is the INTENSITY control. Its proper use gives a good image and prevents burning a hole into the coating on the face of the crt.

The FOCUS control permits the adjustment of the sharpness of the dot, or trace. In addition to this control some scopes may have an ASTIGMATISM control. It ensures that all parts of the waveform will be in focus at the same time.

The HORIZONTAL POSITION control permits the operator to position the dot, or waveshape, to the right or left on the scope face. When used with the VERTICAL POSITION control, which positions the dot up and down, it is possible for the operator to move the dot to any point on the face of the scope.

A CALIBRATED ATTENUATOR control, for vertical deflection, reduces the vertical input signal amplitude. This circuit extends the range of the scope. Using it, a large input voltage can be reduced and measured. Without it the signal would extend off the scope, and damage to the scope could possibly result. Any voltage applied to the vertical plates causes the dot to extend up and down in proportion to the voltage applied.

INPUTS.–A vertical input jack is provided on the front of the scope. The signal to be viewed is normally brought in on the vertical input and goes to the vertical deflection plates. The normal input to the horizontal deflection plates is the sweep voltage from the internal sweep generator. The sweep voltage causes the dot to move from left to right across the screen. As this happens, the signal voltage causes the dot to move up or down as signal amplitude varies until the dot reaches the right side of the screen. At this time, the sweep voltage goes from maximum positive to maximum negative very rapidly, and the dot returns to the left side of the screen. The time required for this return is called FLYBACK TIME (fig. 16-21). A horizontal input jack is provided on the front of the scope for use when the horizontal input signal does not come from the internal generator.

Scopes come equipped with a direct probe, which connects the oscilloscope to the signal to be viewed. Some scopes are equipped with an attenuator probe. The most commonly used attenuator probe is the 10:1. This reduces the input signal to one-tenth of the original value, to extend the voltage range of the scope. A 10:1 attenuator probe reduces a 400-volt input to 40 volts. In this way, the range of the scope is extended.

In addition to vertical deflection, the dot must be extended into a line across the face of the scope horizontally in order to analyze waveshapes. For this, the scope has a SWEEP circuit which causes the spot to sweep across the screen. Actually, the dot is first positioned to the left side of the screen, and then, by electrostatic or electromagnetic fields, the dot is moved from left to right. As soon as it reaches the right side, it is quickly moved back to the left to retrace the path just made. When the dot sweeps across the screen, it appears as a solid line to the eye. The inner surface of the crt screen is coated with a phosphorescent material which glows for a time after the dot has moved; this is called PERSISTENCE of the screen. This rate of movement can be controlled by horizontal sweep circuits inside the scope. It is the horizontal sweep that must be synchronized with the input waveform to cause the input waveform to appear stationary on the face of the scope. Obviously, the horizontal sweep voltage is applied to the horizontal deflection plates (fig. 16-22), and the input waveform is applied to the vertical deflection plates.

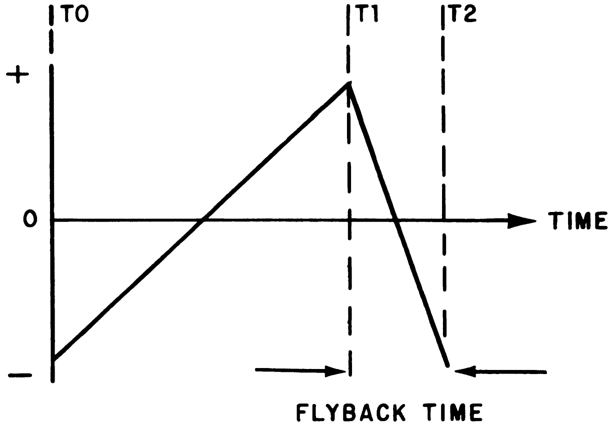

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Figure 16-21.—Flyback time.

MEASURING VOLTAGES.—In measuring voltages with the scope, it must be kept in mind that the scope measures the peak-to-peak value. If the signal is a sine wave, the peak-to-peak value may be converted to the rms or effective value by dividing by 2, which gives the peak value. Then, multiply the peak value by .707 to get the effective value. The peak-to-peak value may also be multiplied by .3535 to obtain the effective value. For example: If the peak-to-peak value is 200 volts, the peak value is 200/2, or 100 volts and .707 X 100, or 70.7 volts effective.

To measure the voltage of a sine wave using a scope with a calibrated square wave, adjust the scope controls until two or three cycles of the sine wave are displayed. Adjust the vertical gain

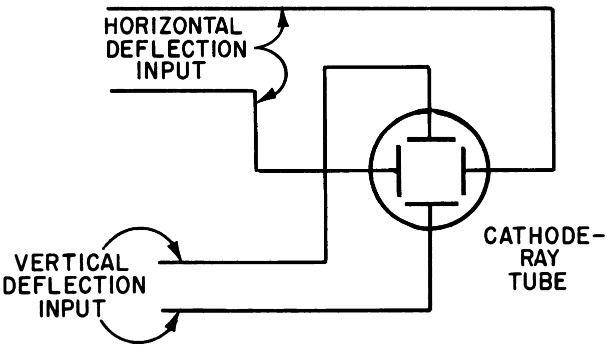

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Figure 16-22.—Deflection inputs.

until the peak-to-peak amplitude extends across two spaces (fig. 16-23A). Now, disconnect the sine wave and apply the square wave. Vary the calibrator control until the square wave touches the same lines at A and B as shown in Figure 16-23B. Read the setting on the calibrator control and multiply this by the multiplier gain setting. If a 10:1 attenuator probe is used, multiply the answer by 10. This is the peak-to-peak value of the voltage. Multiply this value by .3535 to get the effective, or rms value.

If the scope does not have the calibrated square wave, use a known voltage from an external source. Suppose 1 volt is used. Adjust the signal on the scope to one square. (If the voltage is large, use the small squares to keep the signal on the scope. If a small voltage is to be measured, the large squares could possibly be used.) Without changing the controls, remove the known signal and apply the one to be measured. Count the number of spaces the signal extends vertically, and multiply by 1 to obtain the signal voltage. Again, remember that this is a peak-to-peak value and must be converted to obtain the effective value.

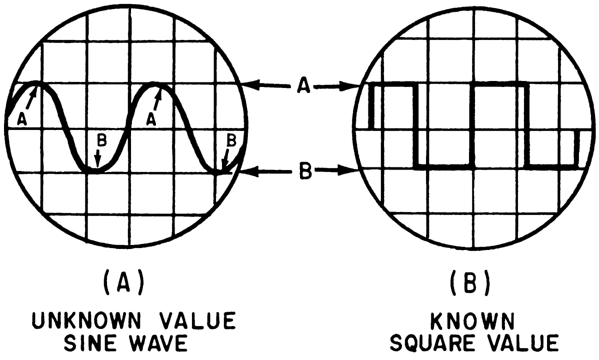

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Figure 16-23.—Amplitude measurement.

MEASURING FREQUENCY.—In figure 16-21, the sweep voltage was shown. If a sine wave applied to the vertical input is at the same frequency, a single cycle of the sine wave will appear on the screen (fig. 16-24). The frequency ratio is 1:1. If two cycles are seen, the signal frequency is two times the sweep frequency. This makes possible a means of determining the frequency of an unknown signal. Or, if the signal frequency is known, you can determine the frequency of the sweep. It is only necessary to know either the signal frequency or the sweep frequency, to obtain the other.

SIGNAL GENERATOR

In the maintenance of electronic equipment, it is often necessary to employ standard sources of a.c. energy, both audio frequency and radio frequency. These sources are called signal generators, and are used in testing, aligning, and troubleshooting various electronic devices and equipment.

The principal function of a signal generator is the production of an alternating voltage of the

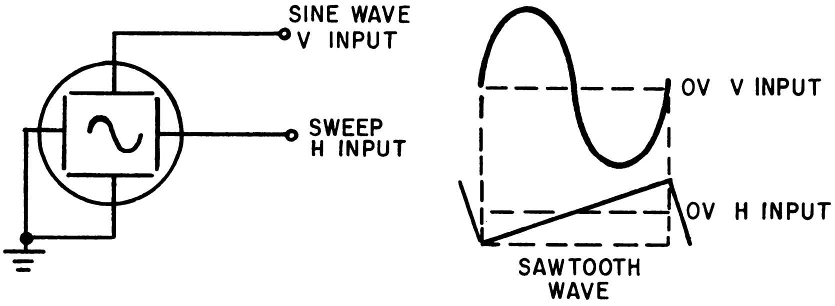

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Figure 16-24.—Frequency measurement.

desired frequency and amplitude which has the necessary modulation for the test or measurement concerned. It is very important that the amplitude of the generated signal be correct. In many generators, output meters are included in the equipment so that the output may be adjusted and maintained at a standard level over a wide range of frequencies.

When using the generator, the output test signal is coupled into the circuit being tested, and its progress through the equipment is traced by the use of high-impedance indicating devices such as vacuum tube voltmeters or oscilloscopes. In many signal generators, calibrated networks of resistors, called attenuators, are provided. These are used to regulate the voltage of the output signal and also provide correct impedance values for matching the input impedance of the circuit under test. Accurately calibrated attenuators are used, as the signal strength must be regulated to avoid overloading the circuit receiving the signal.

There are many types of signal generators. They may be classified roughly by frequency into audio generators, generators of both the audio and video ranges, radio-frequency generators, frequency-modulated rf generators, and special types which combine all of these frequency ranges.

Audio and Video Signal Generators

Audio signal generators (fig. 16-25) produce stable audio-frequency signals used for testing audio equipment. Video signal generators produce signals which include the audio range and extend considerably further into the rf range. These generators are used in testing video amplifiers and other wideband circuits. In both audio and video generators, the major components include a power supply, an oscillator (or oscillators), one or more amplifiers, and an output control.

In the audio and video generators of the beat-frequency type, the output frequency is produced by mixing the signals of two radio-frequency oscillators, one of which is fixed in frequency and the other variable. The difference in frequency of the two is equal to the desired audio or video frequency.

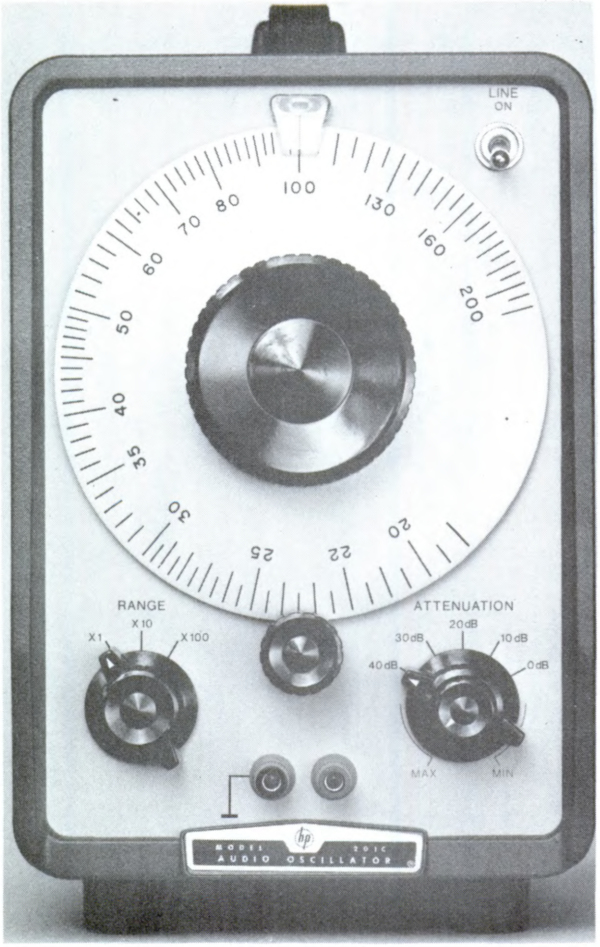

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Figure 16-25.—Audio-frequency (af) signal generator.

Audio signal generators often include RC oscillators in which the audio frequency is directly produced. In these, a resistance-capacitance circuit is the frequency determining part of the oscillator. The frequency varies when either the resistance or the capacitance is changed in value. In commercial generators, however, the capacitance alone is often chosen as the variable element. The change in frequency which can be produced by this method is limited, and it is usually necessary to cover the entire range of the generator in steps. This is accomplished by providing several RC circuits, each corresponding to a portion of the entire range of frequency values. The circuits in the oscillator are switched one at a time to give the desired portion of the audio range.

The amplifier section of the block diagram (fig. 16-26) usually consists of a voltage amplifier and one or two power amplifiers. These are coupled by means of RC networks, and the output of the final power amplifier is often coupled to the attenuator, or output control, by means of an output transformer.

The output control section provides a means of matching the output signal to the input of the equipment under test and regulating the amplitude of the signal.

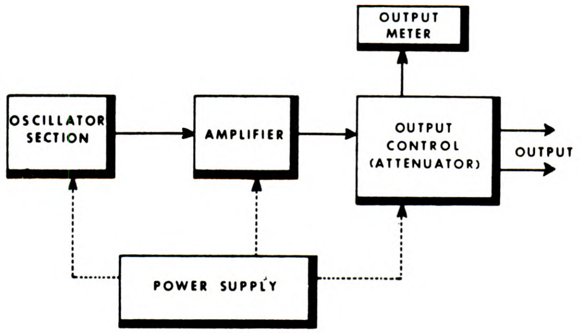

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Figure 16-26.—Block diagram of audio or video signal generator.

Radio-frequency Signal Generators

A typical radio-frequency signal generator (fig. 16-27) contains, in addition to the necessary power supply, three main sections: an oscillator circuit, a modulator, and an output control circuit. The internal modulator modulates the radio-frequency signal of the oscillator. In addition, most rf generators are provided with connections through which an external source of modulation of any desired waveform may be applied to the generated signal. Metal shielding surrounds the unit to prevent the entrance of signals from the oscillator into the circuit under test by means other than through the output circuit of the generator.

A block diagram of a representative rf signal generator is shown in figure 16-28. The function of the oscillator stage is to produce a signal which can be accurately set in frequency at any point in the range of the generator. The type of oscillator circuit used depends on the range of frequencies for which the generator is designed. In low-frequency signal generators, the resonating circuit consists of one of a group of coils combined with variable capacitor. One of the coils is selected with a range selector switch which attaches it to the capacitor to provide an LC circuit which has the correct range of resonant frequencies.

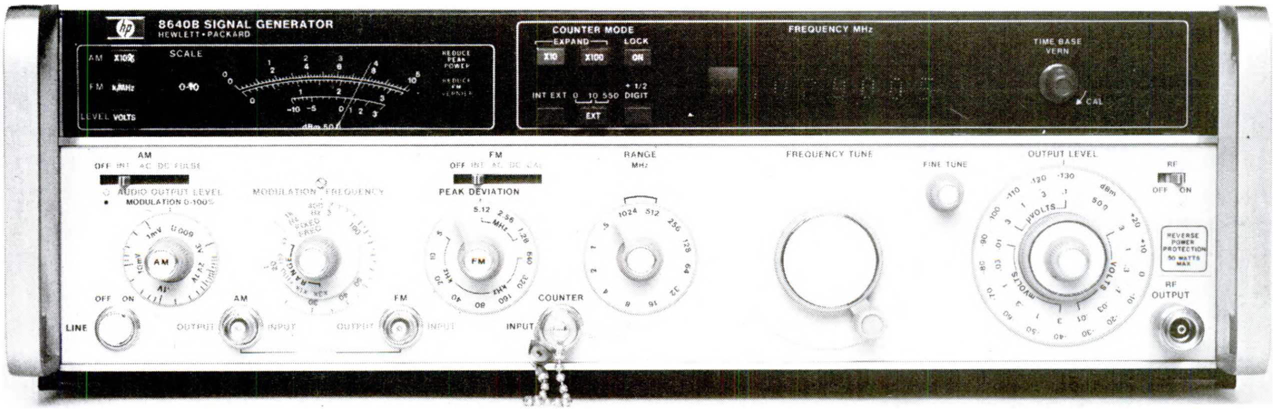

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Figure 16-27.—Radio-frequency (rf) signal generator.

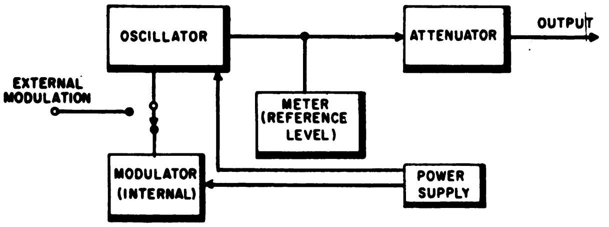

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Figure 16-28.—Block diagram of a radio-frequency signal generator.

The function of the modulating circuit is the production of an audio (or video) voltage which can be superimposed on the rf signal produced by the oscillator. The modulating signal may be provided by an audio oscillator within the generator (internal modulation), or it may be derived from an external source. In some signal generators, either of these methods of modulation may be employed. In addition, a means of disabling the modulator section is used whereby the pure unmodulated signal from the oscillator can be used when it is desired.

The type of modulation used depends on the application of the particular signal generator. The modulating voltage may be either a sine wave, a square wave, or pulses of varying duration. In some specialized generators, provision is made for pulse modulation in which the rf signal can be pulsed over a wide range of repetition rates and at various pulse widths.

Usually the output circuit of the generator contains a calibrated attenuator and often an output level meter. The output level meter gives an indication of, and permits control of, the output voltage of the generator by indicating arbitrary values of output read in tenths through the value of one. The attenuator selects the amount of this output. The attenuator, a group of resistors forming a voltage-dropping circuit, is controlled by a knob which is calibrated in microvolts. When the control element is adjusted so that the output meter reads unity (1.0), the reading on the attenuator knob gives the exact value (no multiplication factor) of the output in microvolts. If output voltage is desired at a lower value, the control is varied until the meter indicates some decimal value less than one; and this decimal is multiplied by the attenuator reading to give the output in microvolts.

Frequency-modulated rf signal generators are widely used for testing frequency-modulated receivers and for visual alignment (using an oscilloscope) of AM receivers. A frequency-modulated signal is an alternating voltage in which the frequency varies above and below a given center frequency value. The overall frequency change is called the frequency swing.

There are several methods by which the frequency of the oscillator in the signal generator may be frequency modulated. In one type of FM generator, use is made of a vibrating plate which forms one of the elements of the tuning capacitor of the oscillator to be modulated. The plate is driven by a device similar to a magnetic loud-speaker. The audio modulating voltage is applied to the driving coil which moves in the field of a permanent magnet and vibrates the plate of the capacitor at the applied audio frequency. Movement of the plate causes variation of the capacitance in the oscillator tuning circuit with the result that the frequency of the oscillator is periodically raised or lowered.

Another method of producing frequency modulation is based on the action of a reactance tube which is connected in parallel with the tuning circuit of the oscillator to be modulated. A reactance tube is an electron tube in which the plate current is made either to lead or to lag the plate voltage variations by 90°. Because of this phase difference, the plate circuit of the tube is electrically equivalent either to a capacitor or to an inductance. The modulating voltage is impressed on the grid of the reactance tube, causing the capacitive (or inductive) reactance of the plate circuit of the tube to vary. Since the reactance tube plate circuit is a part of the oscillator tuning circuit, variation in the reactance value causes the generated frequency to vary in step with the modulating voltage.

In signal generators of microwave frequencies, frequency modulation is accomplished in the oscillator by applying the modulating voltage to the repeller plate of the reflex klystron tube which is usually employed in these generators.

ELECTRONIC COUNTER

Figure 16-29 shows a portable, solid-state electronic counter which is used for precisely measuring and displaying, on a 9-digit numerical readout, the frequency and period of a cyclic electrical signal; the frequency ratio of two signals; the time interval between two points on the same or different signals; and the total number of electrical impulses (totalizing). The counter also provides the following types of output signals:

1. Standard signals from 0.1 Hz to 10 MHz decade steps derived from a 1 MHz frequency standard, frequency dividers, and a frequency multiplier;

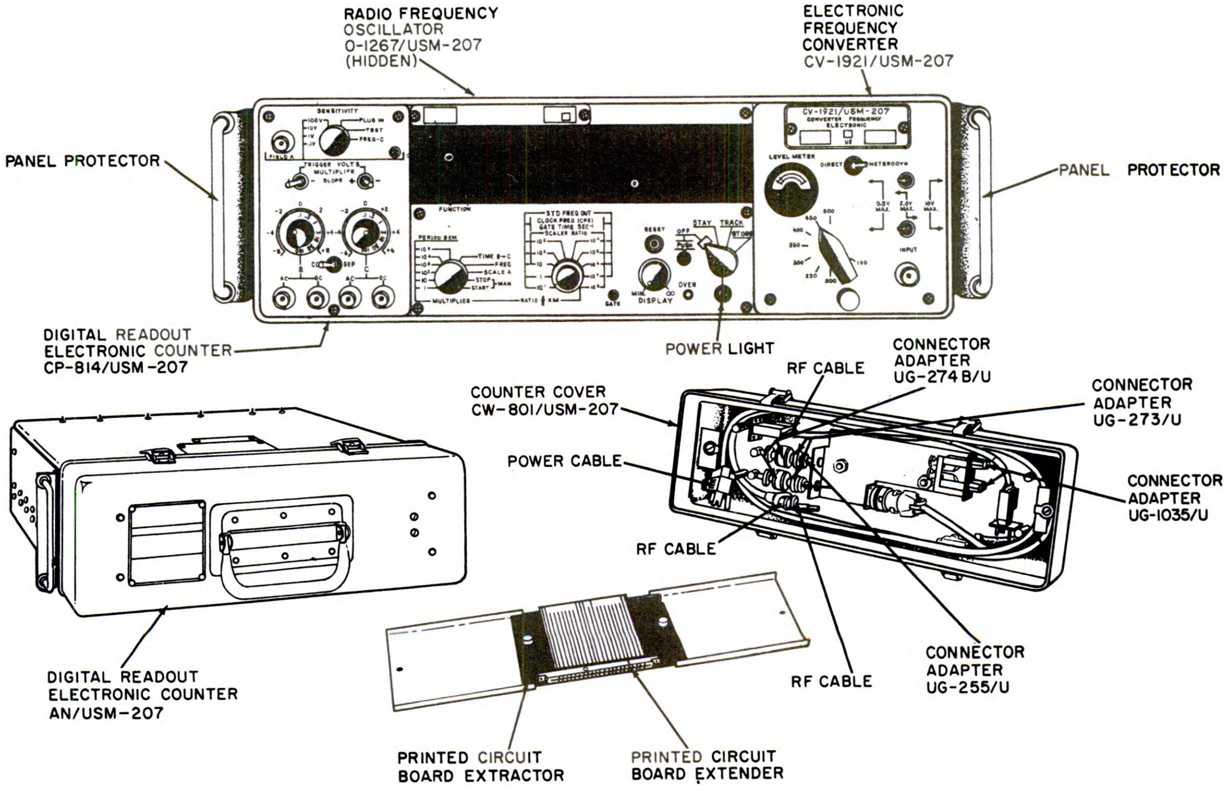
2. Input signals divided in frequency by factors from 10 to 10^8 by a frequency divider;

3. Digital data of the measurement in four-line, binary-coded-decimal form with decimal point and control signals for operation of printers, data recorders, or control devices; and

4. A 1 MHz output from a frequency standard.

This test instrument consists of a major counter assembly, two plug-in assemblies which install in recesses on the front and rear panels, and a group of accessory cables and connectors stored in the detachable front cover.

The major assembly digital readout electronic counter contains the input amplifiers; gate control; display; reset and transfer control; frequency multipliers; time base dividers; decade and readout boards; numerical display tubes; decimal point and units indicators; power supply



162.7

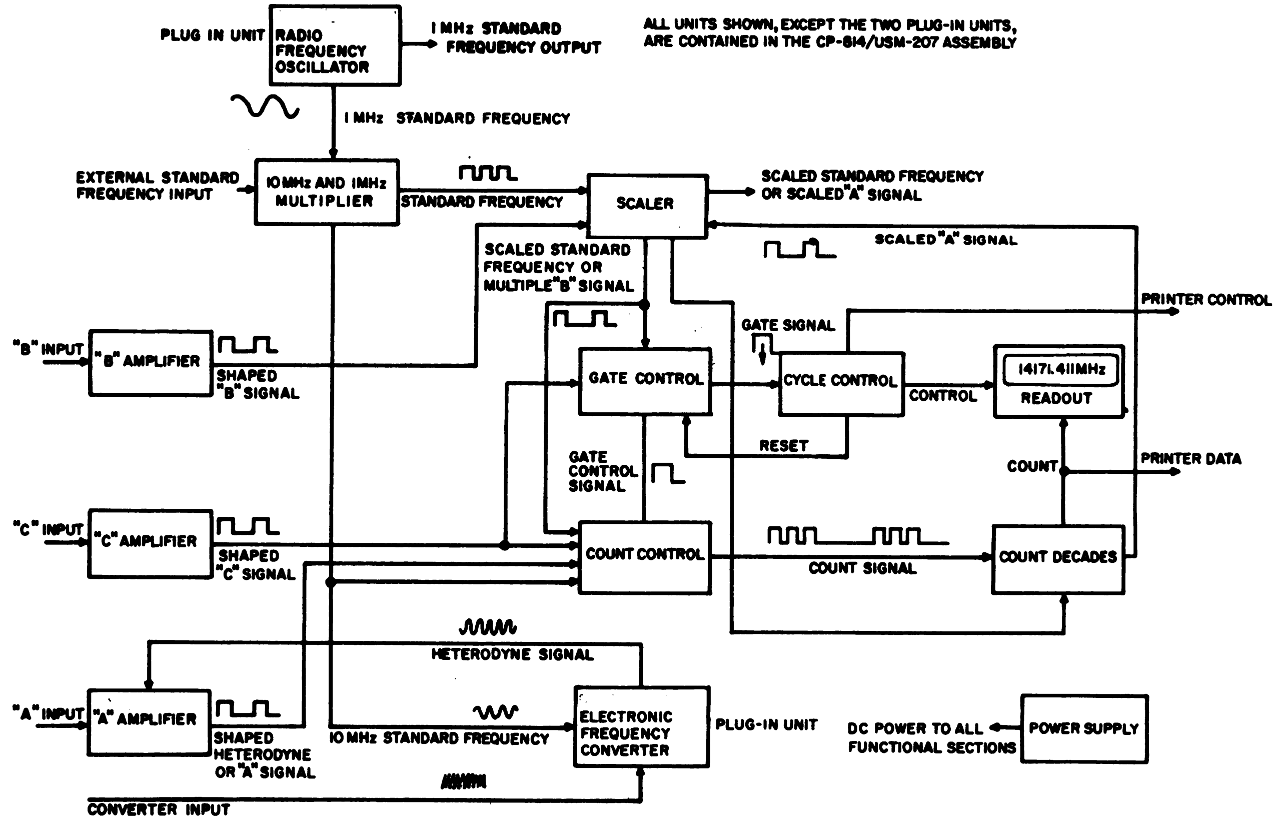
Figure 16-29.—Digital readout electronic counter.

and regulator; and controls associated with these circuits.

The radio-frequency oscillator plug-in assembly develops a 1 MHz signal and includes its own power supply. The oscillator includes the 1 MHz output receptacle which may be used as a source of that frequency when the oscillator is connected to a.c. power through the basic counter or when connected to the power line independently of the counter. The counter may be operated without the oscillator in totalizing, scaling the input signal, time interval with external clock, and frequency ratio measurements. For other measurements, the counter does not require the oscillator when a separate external 100 kHz or 1 MHz signal is connected. In either of these two situations the oscillator may be left in the counter or removed. The oscillator plugs into the right rear of the counter.

The electronic frequency converter plug-in assembly permits measurement of frequencies up to 500 MHz, using the heterodyne principle. The unit consists of the broadband amplifier, mixer, multiplier, and controls and indicators associated with these circuits. When measurements other than heterodyne frequency measurements are made, the converter is not required, but need not be removed. The converter also permits the measurement of signals from 35 MHz to 100 MHz with a greater sensitivity than is available with the basic counter. The converter plugs into the right front of the counter.

Figure 16-30 is the overall functional block diagram of the counter. To make a measurement requires two types of information: a count


PLUG IN UNIT
RADIO FREQUENCY OSCILLATOR
1 MHz STANDARD FREQUENCY OUTPUT
ALL UNITS SHOWN, EXCEPT THE TWO PLUG-IN UNITS, ARE CONTAINED IN THE CP-814/USM-207 ASSEMBLY
1 MHz STANDARD FREQUENCY
EXTERNAL STANDARD FREQUENCY INPUT
10 MHz AND 1 MHz MULTIPLIER
STANDARD FREQUENCY
SCALER
SCALED STANDARD FREQUENCY OR SCALED "A" SIGNAL
SCALED "A" SIGNAL
SCALED STANDARD FREQUENCY OR MULTIPLE "B" SIGNAL
PRINTER CONTROL
GATE SIGNAL
"B" INPUT
"B" AMPLIFIER
SHAPED "B" SIGNAL
GATE CONTROL
CYCLE CONTROL
CONTROL
14171.411MHz
READOUT
RESET
GATE CONTROL SIGNAL
COUNT
PRINTER DATA
"C" INPUT
"C" AMPLIFIER
SHAPED "C" SIGNAL
COUNT CONTROL
COUNT SIGNAL
COUNT DECADES
HETERODYNE SIGNAL
"A" INPUT
"A" AMPLIFIER
SHAPED HETERODYNE OR "A" SIGNAL
10 MHz STANDARD FREQUENCY
ELECTRONIC FREQUENCY CONVERTER
PLUG-IN UNIT
DC POWER TO ALL FUNCTIONAL SECTIONS
POWER SUPPLY
CONVERTER INPUT

162.8

Figure 16-30.—Digital readout electronic counter overall functional block diagram.

signal and a gate control signal. These two signals may be generated within the instrument or they may be supplied from outside sources. The type of measurement the counter will make depends upon the relationship of these two signals. In any function, the instrument counts the count signal for a period of time determined by the gate control signal. Routing of these signals within the instrument is accomplished by logic circuits. These logic circuits are controlled by means of the front panel controls.

The radio-frequency oscillator generates a signal of precise frequency for use throughout the counter, or to provide a precise 1 MHz signal for use outside the equipment.

The electronic frequency converter accepts radio frequencies between 100 MHz and 500 MHz and converts them to radio frequencies between 5 MHz and 100 MHz for measurement by the basic counter.

The "A" amplifier amplifies the A input signal or the output of the converter for use throughout the counter.

The "B" amplifier amplifies and shapes the B input signal for use throughout the counter.

The "C" amplifier amplifies and shapes the C input signal for use throughout the counter.

The 10 MHz and 1 MHz multiplier multiplies the frequency and shapes the signal generated by the radio-frequency oscillator. It also provides precise timing signals to the various functional sections of the basic counter and to the frequency converter.

The scaler consists of a series of decade dividers and gating systems which provide divided standard frequencies and control signals depending on the type of measurement the instrument is making.

The gate control generates the gate control signal. This signal determines the length of time that the count decades count the count signal.

The count control provides the proper count signal to the count decades, as selected by the setting of the front panel switches.

The cycle control produces all signals necessary to display the measurement results on the readout and to recycle the counter.

The count decades count the count signal when permitted to do so by the gate control. The result of their counting becomes the final reading displayed by the readout at the end of each measurement.

The readout receives binary-coded-decimal (BCD) data from the count decades, decodes this data into decimal form, and drives the readout indicator tubes. The readout also contains memory circuits which function when the counter is operated in the "Store" mode.

CHAPTER 17

ADMINISTRATION

As a member of the weapons department, you are a partner in its administration. True, most of your working day is spent on a particular piece of equipment that is but a part of the entire fire control system. Therefore, you probably think of yourself as being subjected to administration rather than being a part of it. Essentially, however, it is your work, ability, and training, plus your equipment, that are being administered; and you have some say in the determination of administrative policies.

The operational and maintenance policies on your equipment are based in part on data obtained from the records and reports that you make. Thus, administration is a tool to aid you, and is well worth the paperwork involved. The assistance you receive from administration is not always apparent; but the paperwork is, and in the name of expediency the paperwork is sometimes disregarded. When this happens everyone suffers, because something is taken away from the organization.

THE IMPORTANCE OF PAPERWORK

In a worldwide operation such as the Navy, involving ships of all sizes, with many different types of equipment installed, and personnel constantly being transferred, administrative paperwork becomes very important. If a person were assigned to, and left with, one type of equipment, or even on one ship for many years, that person might feel that the paperwork in the daily routine is not important. However, the administrative organization of a fire control work center needs the equipment reports and records in order to determine its past operational status and to use this as a reference check, if and when new equipment troubles occur. Then, replacement parts can be made available, alterations to improve the equipment made, training programs planned, and procedures of operation and maintenance are safer, quicker, and more effective. The administrative organization starts within the FT gang and works its way up through the ship's weapons department to the captain, and from the ship through the channels within the fleet organization to the material commands. For each operation, replacement, or maintenance step taken on the equipment, there is paperwork involved which holds the chain of information together.

As an illustration of the paperwork involved, let us take a brief look at one sub-unit of a fire control system—a radar set. Initially, a list identifying all the component sub-units in the radar set is needed. The identification includes such information as the name of the unit, its type, its mark and mod numbers, and its serial number. Any alteration made to a unit, and any ordered alteration received but not performed, must be recorded with the unit's record. This way, we know exactly what the radar set consists of and what its designed capabilities are. Based on this information; performance, operation, and maintenance standards are established for the radar set. A record is kept of the operational performance of and the results of the periodic tests run on the radar. This information is compared with the operating standards to keep a running record of the operability of the radar. Any maintenance performed must be recorded in detail. This information indicates the reliability and maintainability of the radar. It also shows whether a change in the replacement parts carried by the ship or a modification to the radar set is required to eliminate a source of recurring trouble. If a defective part must be replaced, you must initiate the paperwork necessary to obtain the replacement from the supply department. Finally, a record of the personnel assigned to operate and to maintain the radar, their qualifications, training program, and planned replacements must be kept.

This is but a rough sketch of the paperwork involved with one sub-unit in a system. It is sometimes difficult to associate the assistance obtained from administration with the records and reports made out in a daily routine.

Other than the military duties required of all petty officers, your primary professional duty as an FT is keeping the fire control equipment in top working order. As part of your overall duty of maintaining fire control equipment, certain bookkeeping chores are involved.

PUBLICATIONS

There are many publications used in the proper maintenance of fire control equipment. Technical publications issued by the various sections of the Department of the Navy are sources of important information for every person in the Navy. Publications by the Naval Sea (NAVSEA) Systems Command, Naval Material (NAVMAT) Command, and Naval Military Personnel Command (NMPC) concern fire control technicians. The most important publications from these sources with which you should be familiar are discussed in this chapter.

NAVSEA has control of all publications formerly produced by the Naval Ordnance System Command, the Bureau of Naval Weapons, and the Bureau of Ordnance. Although these organizations no longer exist, their publications remain in effect until rewritten or cancelled by NAVSEA; reference to their publications should not be considered as errors.

INSTRUCTIONS AND NOTICES

A system is in use throughout the Navy for the issuance of the directive type of release, including those which prescribe policy, organization, methods, or procedures, and those which contain information. Certain publications, such as established manuals, operation releases, technical publications, some classified matter, and those joint Army-Navy-Air Force publications which are numbered serially, but do not have separate Army or Air Force designation, are excluded from the system.

This program, called the Navy Directives Issuance System, provides a uniform plan for issuing and maintaining directives; conformance to the system is required of all activities and commands of the Navy. Two types of releases are authorized under the plan: instructions and notices.

INSTRUCTIONS are directives which contain information or require action of a continuing nature. An Instruction has permanent reference value and is effective until the originator supersedes or cancels it.

NOTICES are directives of a one-time nature and contain information or require action which can be completed immediately. A Notice does not have permanent reference value and contains provisions for its own cancellation.

For reasons of identification and accurate filing, all directives are identified by the originator's authorized abbreviation; the type of release (whether an Instruction or Notice); a subject classification number; and, in the case of Instructions only, a consecutive number. This information is assigned by the originator and is placed on each page of the release. Because of its temporary nature, a consecutive number is not assigned to a Notice.

The numbering and identifying of directives can be better understood by considering a typical identifier:

NAVSEA	INST	8223.1
(a)	(b)	(c) (d)

(a) Here the authorized abbreviation of the originator of the directive is placed.

(b) This part refers to the type of release, in this case an Instruction.

(c) This is the subject number which is determined by the subject matter of the directive, and is obtained from the Table of Subject Classification Numbers.

(d) Following the period is the consecutive number which is found only on Instructions. An originator would assign consecutive numbers to those consecutive instructions with the same subject classification number. In the preceding example, the subject classification number 8223 concerns a gun director. If the originator issued additional Instructions dealing with this subject, they would be assigned the numbers 8223.2, 8223.3, 8223.4, etc. Subject classification numbers are listed in the Table of Subject Classification Numbers found in SECNAV Instruction 5215 (latest revision). This table contains a numerical and alphabetical listing of numbers with their related subjects, and is of considerable value for reference use when information or instructions of a particular nature are desired. This instruction contains all the necessary information for classifying documents by subject. The major numerical subject group, 8000-8999 (ordnance material) is of special interest to the fire control technician.

A permanent file of instructions that are applicable to the ship is kept in the ship's office. This is the master file of instructions. Specific or subject files are kept in the department offices. Thus, a copy of all the ordnance instructions should be in the weapons office along with a copy of the Consolidated Subject Index (NAVPUBINST 5215 (latest revision)).

ORDNANCE PAMPHLETS

The primary source of technical information on operation, maintenance, adjustment, installation, and servicing of fire control and other ordnance equipment is the Ordnance Pamphlet (OP) series of publications. These are published by direction of NAVSEA, each under its own OP number. There are two categories of OPs: equipment OPs and specific subject OPs.

Equipment OPs

Equipment OPs deal with the effective use of specific ordnance equipment. Each major unit of an ordnance installation is covered by an OP. Equipment OPs are organized according to the following general outline:

Introduction
Theory and functional description
How to operate the equipment
Physical description
Installation and assembly
Maintenance
Overhaul and repair
Appendixes
Index
Safety precautions

The introduction includes a brief explanation of what the equipment is, where it is used, what it is intended to do, and the like, as well as a description of the differences among various modifications, if appropriate.

Normally one chapter is devoted to each heading, though with complex equipment (like the Gun Fire Control System Mk 86) each topic may require an entire volume. Or, if the OP takes up a different assembly or subassembly in each chapter, the outline may be followed, so far as it is applicable, in the individual chapters. So there are variations, but the preceding topic list, or one much like it, shows what information can be found in equipment OPs. When working on fire control equipment, make it a rule to have the applicable OP present for ready reference.

General OPs

General OPs take up a subject matter area rather than a specific item of ordnance equipment. Such OPs, of course, do not follow the preceding standard outline. However, they are written and indexed so as to serve as reference books for instruction and training. A good example of this type of OP is OP 3000 (Volume I), Weapons Systems Fundamentals. This introduces and explains the fundamental principles of weapons and weapons system components.

ORDNANCE DATA

Ordnance Data (ODs) contain routine test and inspection results. Installation and alignment data, parallax data, publications requirements lists, and ordnance equipment lists are normally provided in ODs. Ordnance Data are often an important source of information for maintenance personnel, but an OD should not be used as a substitute for an OP.

INDEX OF ORDNANCE PUBLICATIONS

The Index of Ordnance Publications (NAVSEA OP-0) is a listing of all types of ordnance publications stocked for issue by NAVSEA.

The Index is divided into two parts. The first part is a numerical listing according to the type of publication. This part is a complete numerical listing of all NAVSEA Ordnance Pamphlets (OPs), Ordnance Data (ODs), and Ordnance Supply Office Illustrated Parts Breakdowns (OIs). In addition, it includes current Army Field Manuals (FMs) and Army Technical Manuals (TMs) used by Navy activities. For OPs, ODs and OIs, the active publications and associated data are listed first. Following, is a list of historic publications (those that are known to be cancelled or obsolete).

For active publications, the latest published change and subsequent changes under preparation are shown. Publications in the history file are listed with the latest revision and latest change associated with the publication at the time it was cancelled or superseded.

Part two of NAVSEA OP-0 is a subject listing. This part lists the ordnance publications under the appropriate system, equipment, or general subject area nomenclature. Only publications with code, mark, and mod relationships or general application for shipboard use are addressed in this section.

The contents and description of OP-0 may sound confusing, but it is easy to use.

Use of OP-0

Assume that you are working on a Mk 86 Mod 4 GFCS and you want all the available publications on the system which help make your job easier.

OP-0 is normally kept in the weapons office. Usually, the name and identification data of the equipment is known, rather than the number of a publication. Therefore, start with the name of the equipment, the Fire Control System, Gun Mk 86 Mod 4. The first step toward finding the OPs and ODs on the system is to go to the Subject Listing (Part 2) and look under the equipment's title (Fire Control System, Gun Mk 86 Mod 4). Here you will find two ODs, 43792 and 45432, and six OPs, 3758, 3759, 4044, 4049, 4051, and 4055.

The next step is to find these numbers in the Numerical Listing (Part 1) of OP-0. The pertinent information of the OPs and ODs, such as the title, the number of volumes, the number of revisions, and how many changes have been added, is found in this listing.

NAVSEA FORMS

Forms are issued to provide the easiest, clearest, and most practical method of making reports and keeping records on the equipment. A complete list of all the forms issued by the Navy is contained in NAVSUP Publication 2002, the Navy Stock List of Forms and Publications, which are called Cognizance I (Cog I) items in the supply system. This publication is often referred to as the Cog I Manual and contains the information needed to order NAVSEA forms. It also contains the drawing numbers for OPs, ODs, and other publications on the equipment. The list and the forms are continuously being revised; therefore it would not be practical to include a list of forms applicable to fire control. The reports that must be submitted by your ship are listed in the Type Commander's Instruction (5213 series). This list is determined from the current revision of OPNAVINST 5213.7 which is a consolidated listing of required reports. The types of forms which you will deal with in your daily routine are covered later in this chapter.

ORDNANCE ALTERATIONS

Alterations to ordnance equipment approved by NAVSEA are called ORDALTS. An ORDALT instruction furnishes the necessary information to accomplish the ORDALT while an ORDALT kit provides the material (hardware) needed for the alteration. A metal ORDALT plate is attached to each major piece of ordnance equipment. The ORDALT plate is normally mounted next to the unit's name plate. The number of a completed ORDALT is stamped on the ORDALT plate as a permanent record. The completion of an ORDALT is also recorded in the maintenance history of the equipment.

ORDALTS are numbered consecutively without regard to the applicability of equipment or vessel. A publication called ORDALT 00 is an index of all the ORDALTS that have been issued and that are under preparation. The issued ORDALTS are listed numerically and by the applicable equipment.

Alterations which affect the military characteristics of a ship may be approved only by the Chief of Naval Operations and are called NAVALTS. If a NAVALT affects ordnance equipment, it is called a NAVALT ORDALT. Alterations to change design specifications of the ship's hull or machinery are called SHIPALT.

Ship Armament Inventory List (SAIL)

The Ship Armament Inventory List (SAIL) is a list which indicates a ship's ordnance inventory and ORDALT status. This document is the primary vehicle used to define hardware configuration and is used to assemble PMS (Planned Maintenance System) packages for ordnance equipment. If the SAIL is not kept current, the ship probably will NOT receive an accurate package. Each ship has two copies of the SAIL. Before each scheduled overhaul, one copy should be annotated with ORDALTS that have been completed since the last printing; this copy is sent to NAVSEA 7 months before the scheduled availability. The other copy is kept on board. Revised copies of the SAIL are sent to each ship before an overhaul. After completion of the overhaul, the SAIL is annotated to indicate all changes, deletions, additions, and corrections, and a copy is forwarded to NAVSEA. Changes made at other times are reported on the Ship Armament Inventory List (SAIL) Change Report, NAVSEA Form 8000/2. NAVSEA again revises the SAIL to include the changes made at overhaul. When the revised SAIL is received, destroy the previous one.

OAR Program

The ORDALT Accomplishment Requirement (OAR) is a list issued by NAVSEA about 6 months prior to the overhaul of a ship. It shows the ORDALTS in the order of priority of accomplishment, the estimated manhours required for the accomplishment and the estimated cost of each. Within 2 weeks of receipt of the OAR list, shipboard personnel notify NAVSEA and the overhaul activity of the following:

1. ORDALT material on board.
2. ORDALT material on order but not on board.
3. When applicable, special conditions that may exist to warrant installation of conditional ORDALTS.
4. ORDALTS planned for ship's force accomplishment prior to completion of the overhaul period. Shipboard personnel should refrain from requisitioning material for any ORDALT included on the OAR list unless ship's force accomplishment is planned. NAVSEA and the overhaul activity should be notified of any changes that occur which affect the original report.

Upon receipt of the OAR list and the ship's report of ORDALT material on board, the overhaul activity orders those ORDALTS to be accomplished during the overhaul period.

ORDALT Assistance

ORDALT kits for equipment are procured and distributed under the control of the Naval Ship Weapon Systems Engineering Station (NSWSES). When feasible, ships are brought to a particular ORDALT configuration during a Repair Availability (RAV) or shipyard overhaul period. During these periods, the Naval Ordnance System Support Office (NOSSO) may send ORDALT verification teams aboard ship to assist in determining the ship's ORDALT status/ORDALT requirements. These teams are made up of personnel who are "ORDALT experts."

CHANGES TO THE PUBLICATIONS

The publications are continuously reviewed to keep them up to date. A vast amount of data on the operation, performance, testing, and maintenance of ordnance equipment is received and processed. When new methods are developed after a publication has been issued, a change to the publication is issued. Changes to a publication are numbered consecutively and should be made in that order. When the changes to a publication become too extensive, a revised edition is issued. The Index of Ordnance Publications (OP-0) lists the latest revision and the number of changes to each publication.

Types of Changes

Message Changes (MCs) are issued to correct conditions that are potentially hazardous to personnel, equipment, or ammunition because of faulty documentation. MCs provide NAVSEA with the means of rapidly disseminating urgent change information; this type of change should be made immediately.

Advance Change Notices (ACNs) are informal but technically complete temporary changes to the publications; they are interim changes pending issuance of a formal change. ACN change pages do not replace a page in the manual but are inserted immediately ahead of a corrected page.

Formal Changes (CHs) are replacement pages that are used to correct technical manuals. They incorporate improvements resulting from ORDALTS and SHIPALTS and an accumulation of corrections contained in the MCs and ACNs.

ACCEPTANCE DATA

The ship's acceptance tests which were run when the equipment was installed, together with the factory acceptance test, constitute criteria for evaluating subsequent tests and performance of the equipment. The ship's acceptance test results are copied in a logbook so as to be easily available for future reference.

NAVSEA PUBLICATIONS

NAVSEA is responsible for shipboard equipment—often thought of as ordnance equipment, such as ammunition dredger hoists, some fire control switchboards, and director or mount foundations. Thus, there are NAVSEA publications of interest to the FT. Two NAVSEA publications that contain information used by the FT are discussed here.

Naval Ships' Technical Manual

The Naval Ships' Technical Manual, NAVSEA 0901-LP-XXX-XXXX series, pertains to classes of installed machinery and equipment. The data are in accordance with what is considered the best engineering practice for the operation, maintenance, testing, and safety of the equipment. Since the information deals with classes of equipment, it is general in nature and provides background information that is supplementary to the data contained in the equipment's OPs or ODs.

Electronics Installation and Maintenance Books (EIMB)

The Electronics Installation and Maintenance Books, NAVSEA 0967-LP-XXX-XXXX series, are published by NAVSEA to provide subordinate policies and installation and maintenance information standards for naval electronic equipment. The series is intended to reduce time-consuming research on electronic equipment and circuit theory, and contains a great deal of information of interest to the FT. The series is divided into several volumes. Each volume can be ordered as an individual item.

CLASSIFIED PUBLICATIONS

Many fire control publications are classified, and much of this material is in the confidential category. The security measures required in the handling of classified material are covered in OPNAVINST 5510.1E, titled Department of the Navy Information Security Program Regulation. Generally, the responsibility for handling classified matter involves the receipt of, accounting for, making changes to, and distribution of all such matter. Everyone who has access to classified material must be familiar with the information in this publication.

SHIP's PLAN INDEX

The plans and diagrams of the fire control equipment are the road maps of maintenance. Generally speaking, there are two basic sources of this type of information—the Ship's Plan Index and Ordnance Drawings. The Ship's Plan Index (S.P.I.) is prepared by the shipbuilding yard and is normally maintained aboard ship by the Engineering Office. The S.P.I. lists the wiring diagrams of fire control circuits, and the general arrangement and installation plans of the fire control equipment for your ship. The list does not include diagrams of the equipment's internal arrangements and electrical circuits. Ordnance drawings deal with the internal diagrams.

ORDNANCE DRAWINGS

A master list of drawings is prepared for each major piece of ordnance equipment. This list includes all components of the equipment. Each component is itemized by assemblies, subassemblies, and details on a separate list of drawings (LD).

The identifying number for each component LD is given, together with the general arrangement drawing number, on the master list of drawings for the equipment. Each component list of drawings also shows the special tools required for servicing that component. By reference to the list of drawings and the drawings for the mark and mod of a given assembly or subassembly, it is possible to work down to an individual part and to identify the correct nomenclature, drawing, piece number, design dimensions, tolerances, and all other necessary information.

SUPPLIES

Although the supply department is responsible for supplies, you need to know how to identify what you want to get, how to write out the request, and how to report on your use of the supplies. The publications containing the stock numbers are maintained in the supply department. Cooperation with supply personnel is essential in accomplishing your own duties.

SUPPLY DUTIES OF THE FT

Small quantities of supplies are kept in the weapons department and within the divisions of the weapons department. These are usually frequently used small repair parts. As the materials are used, the FT in charge of the supplies must make replacements. This person has to know how to fill out the request form that is taken to the supply department to requisition supplies. These forms are illustrated and explained in *Military Requirements for Petty Officer 3 & 2,* NAVEDTRA 10056 (latest revision). The same text that gives you information on sources of identification numbers for materials and spare parts. The National Stock Number (NSN) is the most important identification number. All the NSNs are given in the Supply Catalogs, but you may not have to use those to look up a number because the NSN for your equipment is usually given in several other sources. One of these is the COSAL.

COSAL AND WHAT IT MEANS

The Coordinated Shipboard Allowance List (COSAL) is the list of all operating equipment and equipage aboard a particular ship. It has three parts. Part 1 lists the ordnance equipment and the major components, and gives the component identification numbers. Part 2 lists the parts allowed for the ship. The quantity of each and the National Stock Number is given. Anything listed in Part 2 is available aboard ship. Part 3 of the COSAL is the final authorized on-board allowance quantity for a repair part. This is of most use to the Storekeeper. Items that are common to more than one department are totaled in this section. For example, a particular type of switch may be used in various applications on the ship. Part 3 of the COSAL will tell how many are to be on board and how many are allotted to each department.

SOURCES OF ORDNANCE IDENTIFICATION

The publications most often used to identify ordnance material are:

1. The ordnance parts of the Federal Supply Catalog for identifying repair parts for requisitioning.

2. Illustrated Parts Breakdown of Ordnance Equipment (IPB). This publication is prepared by Ships Parts Control Center (SPCC). Each IPB is published for one particular type or piece of equipment, and describes and illustrates the relationship of all assemblies and parts comprising the equipment. IPB 0000 is an index of all IPBs.

3. Coordinated Shipboard Allowance List (COSAL), (previously discussed).

One of the most important sources of identification is the information on nameplates. This may include the manufacturer's name, make or model number, size, voltage, and like information. Identification publications such as manufacturer's technical manuals may help you in identifying an item.

ORDNANCE IDENTIFICATION DATA

Ordnance identification data is important in identifying ordnance items. They should be used on all requests for material if the stock number is not available. This data includes:

The MARK NUMBER, which identifies the particular model of a certain type of ordnance equipment.

A MODIFICATION NUMBER (Mod), which indicates a modification of the basic mark number. Modifications are numbered serially, beginning with zero, for each separate mark.

An IDENTIFYING NUMBER, which is the number assigned to the blueprint plan of an ordnance component or assembly. It may be a drawing number, a list of drawing numbers (LD), a sketch number, or an assembly number.

A PIECE NUMBER, which is a subdivision of the drawing number and identifies by a serial designation every item appearing on a given drawing. Sometimes the drawing and piece numbers are stamped or etched on the part itself. Piece numbers are rarely used in later type ordnance assembly drawings. It is now standard practice that each item in a drawing will have its own separate drawing number.

A revision letter is often added to identify a particular revision of a drawing or list of drawings used in the manufacture of a part.

MANDATORY TURN-IN REPAIRABLES

Since you will no doubt encounter the terms "mandatory turn-ins" and "repairables" in the process of obtaining replacement parts from supply, it will be helpful if you understand the purpose of the program and your responsibilities within it.

When any of your equipment fails, your primary concern is to locate the trouble, correct it, and get the equipment "back on the line." In most instances this involves tracing the trouble to a defective part, obtaining the replacement part from the supply storeroom and installing it, and throwing away the defective part. When the defective part is expensive and repairable, we encounter the repairables program.

A large number of parts can be economically repaired when they fail. This results in savings of dollars and time since it is quicker and cheaper to repair an item than to contract for and buy a new one—provided that the old item is promptly returned in repairable condition. For the program to work as intended, you and others have certain responsibilities. At the time your request for a mandatory turn-in item is presented to supply, they must inform you that the item is to be returned. At this point your responsibilities begin. You are required to:

- Remove the defective part without damaging it.

- Provide adequate protection to the part so that it will not be further damaged before it is turned in to supply. The most effective way, for all concerned, is to place the defective part in the same container in which you received the replacement part.

- Resist the temptation to cannibalize the part for components which you might possibly use sometime in the future.

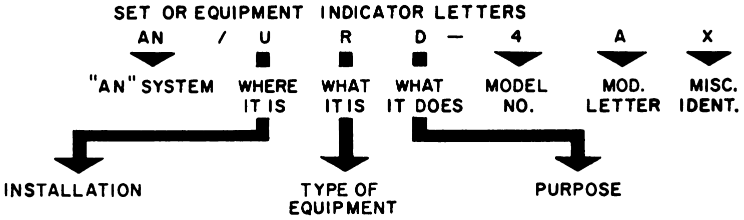
- Return the defective part to supply as soon as practicable.

When the needed part is not in the storeroom, supply must then take steps to obtain it. The failed part must still be returned and should be turned in prior to receiving the replacement part. This way the failed part can enter the repair cycle and be available for reissue soon. The only exception is when the failed part permits limited operation of equipment until the replacement is received.

"AN" NOMENCLATURE SYSTEM

The AN nomenclature, figure 17-1, was designed so that a common designation could be used for Army, Navy, and Air Force equipment. The system indicator AN does not mean that the Army, Navy, and Air Force use the equipment, but means that the type number was assigned in the AN system.

AN nomenclature is assigned to complete sets of equipment and major components of military design; groups of articles of either commercial or military design which are grouped for military purposes; major articles of military design which are not part of or used with a set; and commercial articles when nomenclature will not facilitate military identification and/or procedures.



A--AIRBORNE (INSTALLED AND OPERATED IN AIRCRAFT).
B--UNDERWATER MOBILE, SUBMARINE.
C--AIR TRANSPORTABLE (INACTIVATED, DO NOT USE).
D--PILOTLESS CARRIER.
F--FIXED.
G--GROUND, GENERAL GROUND USE (INCLUDES TWO OR MORE GROUND-TYPE INSTALLATIONS).
K--AMPHIBIOUS.
M--GROUND, MOBILE (INSTALLED AS OPERATING UNIT IN A VEHICLE WHICH HAS NO FUNCTION OTHER THAN TRANSPORTING THE EQUIPMENT).
P--PACK OR PORTABLE (ANIMAL OR MAN).
S--WATER SURFACE CRAFT.
T--GROUND, TRANSPORTABLE.
U--GENERAL UTILITY (INCLUDES TWO OR MORE GENERAL INSTALLATION CLASSES, AIRBORNE, SHIPBOARD, AND GROUND).
V--GROUND, VEHICULAR (INSTALLED IN VEHICLE DESIGNED FOR FUNCTIONS OTHER THAN CARRYING ELECTRONIC EQUIPMENT, ETC., SUCH AS TANKS).
W--WATER SURFACE AND UNDERWATER.

A--INVISIBLE LIGHT, HEAT RADIATION.
B--PIGEON.
C--CARRIER.
D--RADIAC.
E--NUPAC.
F--PHOTOGRAPHIC.[1]
G--TELEGRAPH OR TELETYPE.
I--INTERPHONE AND PUBLIC ADDRESS.
J--ELECTROMECHANICAL OR INERTIAL WIRE COVERED.
K--TELEMETERING.
L--COUNTERMEASURES.
M--METEOROLOGICAL.
N--SOUND IN AIR.
P--RADAR.
Q--SONAR AND UNDERWATER SOUND.
R--RADIO
S--SPECIAL TYPES, MAGNETIC, ETC., OR COMBINATIONS OF TYPES.
T--TELEPHONE (WIRE).
V--VISUAL AND VISIBLE LIGHT.
W--ARMAMENT (PECULIAR TO ARMAMENT, NOT OTHERWISE COVERED).
X--FACSIMILE OR TELEVISION.
Y--DATA PROCESSING.

A--AUXILIARY ASSEMBLIES (NOT COMPLETE OPERATING SETS USED WITH OR PART OF TWO OR MORE SETS OR SETS SERIES).
B--BOMBING.
C--COMMUNICATIONS (RECEIVING AND TRANSMITTING).
D--DIRECTION FINDER, RECONNAISSANCE, AND/OR SURVEILLANCE.
E--EJECTION AND/OR RELEASE.
G--FIRE-CONTROL OR SEARCHLIGHT DIRECTING.
H--RECORDING AND/OR REPRODUCING (GRAPHIC METEOROLOGICAL AND SOUND).
K--COMPUTING.
L--SEARCHLIGHT CONTROL (INACTIVATED, USE G).
M--MAINTENANCE AND TEST ASSEMBLIES (INCLUDING TOOLS).
N--NAVIGATIONAL AIDS (INCLUDING ALTIMETERS, BEACONS, COMPASSES, RACONS, DEPTH SOUNDING, APPROACH, AND LANDING).
P--REPRODUCING (INACTIVATED, DO NOT USE).
Q--SPECIAL, OR COMBINATION OF PURPOSES.
R--RECEIVING, PASSIVE DETECTING.
S--DETECTING AND/OR RANGE AND BEARING, SEARCH.
T--TRANSMITTING.
W--AUTOMATIC FLIGHT OR REMOTE CONTROL.
X--IDENTIFICATION AND RECOGNITION.

[1] NOT FOR US USE EXCEPT FOR ASSIGNING SUFFIX LETTERS TO PREVIOUSLY NOMENCLATURED ITEMS.

20.484

Figure 17-1.—AN system.

AN nomenclature is not assigned to articles cataloged commercially except as stated above, minor components of military design for which other adequate means of identification are available, small parts such as capacitors and resistors, and articles having other adequate identification in joint military specifications. Nomenclature assignments remain unchanged regardless of later changes in installation and/or application.

As an example, we will use the Radar Set, AN/SPG-53F of the MK 68 GFCS:

1. AN - AN system
2. S - where it is - water surface craft
3. P - what it is - radar
4. G - what it does - fire control
5. 53 - model number
6. F - modification letter

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NONRESIDENT CAREER COURSE

FIRE CONTROL TECHNICIAN G 3&2

NAVEDTRA 10207-B

Prepared by the Naval Education and Training Program Development
Center, Pensacola, Florida

Your NRCC contains a set of assignments and perforated answer sheets. The Rate Training Manual, Fire Control Technician G 3&2, NAVEDTRA 10207-B , is your textbook for the NRCC. If an errata sheet comes with the NRCC, make all indicated changes or corrections. Do not change or correct the textbook or assignments in any other way.

HOW TO COMPLETE THIS COURSE SUCCESSFULLY

Study the textbook pages given at the beginning of each assignment before trying to answer the items. Pay attention to tables and illustrations as they contain a lot of information. Making your own drawings can help you understand the subject matter. Also, read the learning objectives that precede the sets of items. The learning objectives and items are based on the subject matter or study material in the textbook. The objectives tell you what you should be able to do by studying assigned textual material and answering the items.

At this point you should be ready to answer the items in the assignment. Read each item carefully. Select the BEST ANSWER for each item, consulting your textbook when necessary. Be sure to select the BEST ANSWER from the subject matter in the textbook. You may discuss difficult points in the course with others. However, the answer you select must be your own. Remove a perforated answer sheet from the back of this text, write in the proper assignment number, and enter your answer for each item.

Your NRCC will be administered by your command or, in the case of small commands, by the Naval Education and Training Program Development Center. No matter who administers your course you can complete it successfully by earning a 3.2 for each assignment. The unit breakdown of the course, if any, is shown later under Naval Reserve Retirement Credit.

WHEN YOUR COURSE IS ADMINISTERED BY LOCAL COMMAND

As soon as you have finished an assignment, submit the completed answer sheet to the officer designated to grade it. The graded answer sheet will not be returned to you.

If you are completing this NRCC to become eligible to take the fleetwide advancement examination, follow a schedule that will enable you to complete all assignments in time. Your schedule should call for the completion of at least one assignment per month.

Although you complete the course successfully, the Naval Education and Training Program Development Center will not issue you a letter of satisfactory completion. Your command will make an entry in your service record, giving you credit for your work.

WHEN YOUR COURSE IS ADMINISTERED BY THE NAVAL EDUCATION AND TRAINING PROGRAM DEVELOPMENT CENTER

After finishing an assignment, go on to the next. Retain each completed answer sheet until you finish all the assignments in a unit (or in the course if it is not divided into units). Using the envelopes provided, mail your completed answer sheets to the Naval Education and Training Program Development Center where they will be graded and the score recorded. Make sure all blanks at the top of each answer sheet are filled in. Unless you furnish all the information required, it will be impossible to give you credit for your work. The graded answer sheets will not be returned.

The Naval Education and Training Program Development Center will issue a letter of satisfactory completion to certify successful completion of the course (or a creditable unit of the course). To receive a course-completion letter, follow the directions given on the course-completion form in the back of this NRCC.

You may keep the textbook and assignments for this course. Return them only in the event you disenroll from the course or otherwise fail to complete the course. Directions for returning the textbook and assignments are given on the book-return form in the back of this NRCC.

PREPARING FOR YOUR ADVANCEMENT EXAMINATION

Your examination for advancement is based on the Occupational Standards for your rating as found in the MANUAL OF NAVY ENLISTED MANPOWER AND PERSONNEL CLASSIFICATIONS AND OCCUPATIONAL STANDARDS (NAVPERS 18068). These Occupational Standards define the minimum tasks required of your rating. The sources of questions in your advancement examination are listed in the BIBLIOGRAPHY FOR ADVANCEMENT STUDY (NAVEDTRA 10052). For your convenience, the Occupational Standards and the sources of questions for your rating are combined in a single pamphlet for the series of examinations for each year. These OCCUPATIONAL STANDARDS AND BIBLIOGRAPHY SHEETS (called Bib Sheets), are available from your ESO. Since your textbook and NRCC are among the sources listed in the bibliography, be sure to study both as you take the course. The qualifications for your rating may have changed since your course and textbook were printed, so refer to the latest edition of the Bib Sheets.

NAVAL RESERVE RETIREMENT CREDIT

This course is evaluated at 24 Naval Reserve retirement points. Points for satisfactory completion of each creditable unit will be assigned as of the date the last assignment of the unit is mailed. Points for creditable units will be assigned as follows:

UNIT	POINTS	ASSIGNMENTS
1	12	1 through 8
2	12	9 through 16

These points are creditable to personnel eligible to receive them under current directives governing the retirement of Naval Reserve personnel. Credit cannot be given again for this course if the student has previously received credit for completing any Fire Control Technician G 3&2 course.

COURSE OBJECTIVE

The objective of this course is to help the individual meet the occupational standards that apply to Fire Control Technician G 3&2. By completing this course satisfactorily, and working conscientiously toward achieving the objective, the student will acquire much of the knowledge needed by a member of the FTG weapons team to:

1. Interpret electrical, electronic, and fire control principles as they are applied in the Gunnery Fire Control System.
2. Operate, test, repair, and maintain equipment of the Gunnery Fire Control System, as typically performed by third and second class Fire Control Technicians G, under supervision.

While working on this correspondence course, you may refer freely to the text. You may seek advice and instruction from others on problems arising in the course, but the solutions submitted must be the result of your own work and decisions. You are prohibited from referring to or copying the solutions of others, or giving completed solutions to anyone else taking the same course.

Naval courses may include a variety of questions -- multiple-choice, true-false, matching, etc. The questions are not grouped by type; regardless of type, they are presented in the same general sequence as the textbook material upon which they are based. This presentation is designed to preserve continuity of thought, permitting step-by-step development of ideas. Some courses use many types of questions, others only a few. The student can readily identify the type of each question (and the action required) through inspection of the samples given below.

MULTIPLE-CHOICE QUESTIONS

Each question contains several alternatives, one of which provides the best answer to the question. Select the best alternative, and blacken the appropriate box on the answer sheet.

SAMPLE

s-1. The first person to be appointed Secretary of Defense under the National Security Act of 1947 was
1. George Marshall
2. James Forrestal
3. Chester Nimitz
4. William Halsey

Indicate in this way on the answer sheet:

	1 T	2 F	3	4	
s-1	☐	■	☐	☐	___

TRUE-FALSE QUESTIONS

Mark each statement true or false as indicated below. If any part of the statement is false the statement is to be considered false. Make the decision, and blacken the appropriate box on the answer sheet.

SAMPLE

s-2. Any naval officer is authorized to correspond officially with any systems command of the Department of the Navy without his commanding officer's endorsement.

Indicate in this way on the answer sheet:

	1 T	2 F	3	4	
s-2	☐	■	☐	☐	___

MATCHING QUESTIONS

Each set of questions consists of two columns, each listing words, phrases or sentences. The task is to select the item in column B which is the best match for the item in column A that is being considered. Items in column B may be used once, more than once, or not at all. Specific instructions are given with each set of questions. Select the numbers identifying the answers and blacken the appropriate boxes on the answer sheet.

SAMPLE

In questions s-3 through s-6, match the name of the shipboard officer in column A by selecting from column B the name of the department in which the officer functions.

A

s-3. Damage Control Assistant

s-4. CIC Officer

s-5. Disbursing Officer

s-6. Communications Officer

B

1. Operations Department
2. Engineering Department
3. Supply Department

Indicate in this way on the answer sheet:

	1 T	2 F	3	4	
s-3	☐	■	☐	☐	___
s-4	■	☐	☐	☐	___
s-5	☐	☐	■	☐	___
s-6	■	☐	☐	☐	___

Assignment 1

FTG Rating, and Data Transmission

Textbook Assignment: FTG 3 & 2, NAVEDTRA 10207-B; pages 1-1 through 2-14

Learning Objective: State the purpose and functions of a fire control technician in the gun fire control rating.

1-1. What is the primary purpose of the Fire Control Technician G 3 & 2 Rate Training Manual?

1. To help you advance to the next higher paygrade
2. To help you meet the occupational standards that apply to the FTG
3. To give you a technical background
4. To help you pass the advancement examination

1-2. What is meant by the term "fire control"?

1. Controlling fires aboard ship
2. Maintaining fire fighting equipment
3. Directing the ship's weapons to hit a desired target
4. Controlling the fire under the ship's boilers

1-3. To which of the following departments aboard ship is an FT most likely to be assigned?

1. Weapons
2. Supply
3. Operations
4. Deck

1-4. Who has primary responsibility for the operation and maintenance of all weapons, weapons system components, and deck gear?

1. The Weapons Officer
2. The First Lieutenant
3. The leading Fire Control Technician
4. The leading Boatswain's Mate

1-5. An FTG striker aboard ship should NOT be required to perform which of the following duties?

1. Read blueprints
2. Requisition parts
3. Boresight guns
4. Supervise personnel

1-6. Personnel must stand watches for which of the following reasons?

1. To continue a Navy tradition
2. To maintain a 24-hour vigilance
3. To improve training
4. To affect morale

1-7. What is a "Dog" watch?

1. An early morning watch
2. A double watch
3. A shortened watch
4. A midnight watch

1-8. Where should your place in the ship's organization and your stations for the various shipboard drills be listed?

1. In the fire control smooth log
2. In the ship's personnel manning list
3. In the supply inventory list
4. In the Watch Quarter and Station bill

1-9. What total number of ship's conditions of readiness are there?

1. Seven
2. Six
3. Five
4. Four

1-10. Under what condition of readiness are NO weapon batteries manned?

1. I
2. II
3. III
4. IV

1-11. What condition of readiness is the same as general quarters?

1. I
2. II
3. III
4. IV

1-12. General quarters is sounded under which of the following circumstances?

1. An aircraft is spotted
2. Another ship is spotted
3. The ship is in danger of immediate attack
4. The ship detects a target on search radar

1-13. What must you do when GQ is sounded?

1. Continue whatever you are doing
2. Contact your supervisor for instructions
3. Stop whatever you are doing and take cover
4. Stop whatever you are doing and go to your assigned battle station

1-14. Maintenance is a primary part of an FT's duties for which of the following reasons?

1. It prevents breakdowns
2. It saves money and time
3. It increases operational safety
4. Each of the above

1-15. On an average, the time required for all the maintenance work that should be performed can be described by which of the following phrases?

1. Requires several days of preparation
2. Takes only one day to complete
3. Can be completed in a relatively small part of each day
4. Consumes a large part of each day

1-16. A daily maintenance work program is the best insurance against which of the following problems?

1. The high cost of replacement parts
2. A breakdown at a crucial moment
3. The need for periodic alignment
4. Ancillary equipment malfunctions

1-17. Components of the weapons system aboard ship are designed to have which of the following characteristics?

1. A long life expectancy
2. Safety cutouts
3. Easy replacement features
4. Each of the above

1-18. Which of the following is a purpose of equipment maintenance?

1. Keep wear and tear to a minimum
2. Keep personnel aware of equipment status
3. Maintain training at an efficient level
4. Each of the above

1-19. Which of the following materials causes the most damage to the metal surfaces of fire control equipment?

1. Fresh water
2. Oil
3. Dirt
4. Wax

1-20. The required repairs and servicing of fire control equipment is dependent upon which of the following factors?

1. The right supplies and spare parts
2. Knowledge of the supply system ordering procedures
3. Proper storage of spare parts
4. All of the above

1-21. How is the large-scale distribution of parts and supplies effectively directed?

1. By standardization of procedures and paperwork
2. By direction of the division officer
3. By each unit developing its own methods
4. By obtaining signatures of approval

1-22. The ability to read schematics and use test equipment is essential to which of the following actions?

1. Maintaining equipment status logs
2. Ordering spare parts
3. Equipment alterations
4. Preparing a maintenance schedule

1-23. What is the purpose of periodic inspections of the system's physical components?

1. To determine operational accuracy
2. To locate inoperative electronic components
3. To fulfill administrative requirements
4. To locate developing deterioration of components

1-24. Which of the following problems can be located by performance testing?

1. Cracked insulation
2. A weak tube
3. A corroded contact
4. A loose electrical connection

Learning Objective: Describe the function of a gun weapon system and its various components.

1-25. According to the text, what is the function of a gun weapon system?

1. Achieving battle victories
2. Delivering destructive power against ships, aircraft, and shore targets
3. Shore bombardment
4. Each of the above

1-26. Why are gun weapon systems constantly changing?

1. New personnel are always reporting aboard
2. New ships need new systems
3. New technologies lead to change
4. Gun weapon systems have been perfected

1-27. The function of a fire control director is to

1. transmit target position from the search radar
2. yield solutions for the gun
3. establish target range
4. locate the position of a target

1-28. Fire control radar uses echoes of high-frequency radio pulses to establish continuous values of target

1. range
2. bearing
3. elevation
4. speed

1-29. Stabilization is accomplished in a stable element by which of the following devices?

1. Gyroscope
2. Magnetic amplifier
3. Electronic tube
4. Synchro

1-30. The function of designation equipment is to

1. direct various weapons so that they will hit the desired target
2. transmit target position from the ship's search radar to a fire control system
3. yield solutions in the form of position signals
4. establish continuous values of target range

1-31. Which of the following elements of a gun mount, if any, are you as an FT expected to maintain?

1. The projectiles
2. The mechanical components
3. The electronic components
4. None of the above

Learning Objective: Describe the basic data transmission system used in fire control systems, and explain the construction and theory of operation of synchro transmitters and receivers.

1-32. Where are components of the gun fire control system located aboard ship?

1. Above deck only
2. Below deck only
3. All in one area
4. In many different areas

1-33. All of the components of the fire control system must be made to work together for which of the following reasons?

1. To ensure that the transmission of data will occur
2. To ensure that the fire control problem may be solved and enemy action neutralized
3. To ensure that the sequence of events can be predicted
4. To ensure that fire control personnel and fire control equipment can work together

1-34. Refer to figure 2-1 of the text. Which of the following data is transmitted from the radar to the computer?

1. Target range
2. Target bearing
3. Target elevation
4. Each of the above

1-35. Which of the following is the maximum distance data may be transmitted to gun fire control equipment aboard ship?

1. 50 feet
2. 100 feet
3. 150 feet
4. Several hundred feet

1-36. A basic data transmission system consists of which of the following elements?

1. A transmission medium, a conductor, and a load
2. A transmitter, a transmission medium, and a conductor
3. A transmitter, a conductor, and a receiver
4. A transmission medium, a receiver, and a load

IN ANSWERING QUESTIONS 1-37 THROUGH 1-39, REFER TO FIGURE 2-3 OF THE TEXT.

1-37. What information can be transmitted by the circuit?

1. Complex signals
2. Mechanical signals
3. An order or an indication of a condition
4. Hydraulic signals

1-38. What component in "A" is the transmitter?

1. The switch
2. The light
3. The conductors
4. The relay

1-39. What component in "B" is the receiver?

1. The switch
2. The relay
3. The motor
4. The wire

1-40. Electrical values and mechanical positions can be used to represent which of the following fire control quantities?

1. Numerical values
2. Quantitative values
3. Yes-no values
4. Each of the above

1-41. A shift in scale in types of measure, such as miles to yards, degrees to minutes, and the like is possible as long as which of the following relationships is true?

1. The shift causes a nonlinear change in results
2. The ratio between the units of measure is constant throughout their range
3. The ratio between the units of measure varies throughout their range
4. The ratio between the units of measure is nonproportional

1-42. Which of the following characteristics is common to all synchros?

1. Rotor windings
2. "Y"-connected stators
3. Transformer principle operation
4. Each of the above

1-43. What is the maximum number of ways synchros can sense position?

1. Five
2. Two
3. Three
4. Four

1-44. What is the maximum voltage that can be induced across any one stator winding of a 115-volt synchro?

1. 0 volt
2. 26 volts
3. 52 volts
4. 78 volts

1-45. The angle of rotor displacement is measured from the center of what winding?

1. S1 winding
2. S2 winding
3. S3 winding
4. Rotor winding

IN ANSWERING QUESTIONS 1-46 THROUGH 1-49, REFER TO TABLE 2-1 OF THE TEXT.

TO ANSWER QUESTIONS 1-46 THROUGH 1-48, SELECT FROM COLUMN B THE SYNCHRO TYPE THAT IS DESCRIBED BY THE INPUT AND OUTPUT CIRCUIT ARRANGEMENTS IN COLUMN A.

	A. ARRANGEMENTS	B. TYPE
1-46.	One mechanical input and one electrical output	1. Torque transmitter (TX)
		2. Torque Differential Transmitter (TDX)
1-47.	One electrical input and one mechanical output	3. Torque Receiver (TR)
1-48.	Two electrical inputs and one mechanical output	4. Torque Differential Receiver (TDR)

1-49. Which of the following types of synchros has one electrical and one mechanical input with an electrical output?

1. Control Differential Transmitter (CDX)
2. Control Transformer (CT)
3. Control Transmitter (CX)
4. Torque Differential Receiver (TDR)

1-50. What is the designation code of a standard synchro that is 2 inches in diameter, is a control transmitter using 400 cycles, and has had 2 modifications?

1. 2CT42
2. 2CX42
3. 20CT4b
4. 20CX4b

1-51. To find the complete identification of a standard Navy synchro used in a piece of fire control equipment, you should look at which of the following references?

1. Schematic diagram of the equipment
2. Wiring diagram of the equipment
3. Isometric drawing of the equipment
4. Physical description section of the OP

Learning Objective: State the reasons for synchro alignment and describe methods of zeroing synchros.

1-52. In order to fulfill its primary function of correctly transmitting information between remote units, a synchro system must have which of the following characteristics?

1. A reference point common to both units
2. A common unit of measure
3. Both transmitting and receiving systems aligned to the same electrical and mechanical reference point
4. All of the above

1-53. The mechanical and electrical zero reference position of a synchro is the axis of what winding?

1. S1 winding
2. S2 winding
3. S3 winding
4. Rotor winding

1-54. What relationship must exist between a synchro system and the transmitting and receiving instruments the system serves?

1. They must be electrically in phase
2. They must be mechanically aligned
3. They must be physically separated
4. The stator winding must be coincident

1-55. What relationship must exist between the voltage from S2 to S3 or S1 and the voltage from R1 and R2, when a synchro is at electrical zero and the voltage from S1 to S3 is zero?

1. In phase
2. Same value
3. 180° out of phase
4. Twice the amplitude

1-56. Where would the alignment of a synchro system logically start?

1. In the stator windings
2. At the receiver for the transmitted quantity
3. In the rotor windings
4. At the origin of the transmitted quantity

1-57. What technical manual should be consulted for methods of adjusting all types of synchros under various conditions?

1. FTG 3 & 2 NAVEDTRA 10207 (Series)
2. The Fire Control System OP
3. Basic Electricity Vol. 1
4. The Military Standardization Handbook MIL-HDBK-225(AS)

1-58. What does the term "electrical error" mean when used in reference to a synchro?

1. The difference between S1 and S3 voltages
2. The difference between R1 and S2 voltages
3. The difference between the actual physical position and the electrical position of the rotor
4. The difference between the physical position of the rotor and the reference stator

1-59. What is the maximum possible accumulated electrical error of a synchro system consisting of two synchros that have an electrical error of 18 minutes apiece?

1. 0 min
2. 18 min
3. 30 min
4. 36 min

1-60. When a null dial reading is obtained from a receiver rotor that is close to, but NOT at, the same angular position of the transmitter rotor, you are using what kind of system?

1. A coarse system
2. A fine system
3. A 36:1 system
4. A null system

1-61. Refer to figure 2-7C of the text. Assume that the gear ratio between the synchro rotors and their handcranks is 72:1 with the same 36 minute electrical error. How far, if at all, must the handcrank for the CT be rotated to drive the rotor of the CT to its null position?

1. 1 minute
2. 36 minutes
3. 30 seconds
4. No rotation

1-62. The advantage of a 36:1 synchro transmission over a 1.1 synchro transmission is that in the 36:1 synchro transmission the output

1. shaft is synchronized with the input shaft at only one position
2. signal must be combined with a coarse system to be self-synchronous
3. shaft may synchronize in steps of 10 degrees for any one position of the input shaft
4. shaft has only to turn one minute for every error of 36 minutes of the input shaft

1-63. The disadvantage of a 36:1 synchro transmission is that the output shaft

1. is synchronized with the input shaft at only one position
2. can be in correspondence at 36 different points for any one revolution of the input shaft
3. has to turn one minute for every error of 36 minutes of the input shaft
4. has to turn 30 seconds for every error of 36 minutes of the input shaft

Learning Objective: Describe dual speed systems, and state their advantage. List the purposes of stickoff voltage.

1-64. When does the fine synchro in a dual-synchro system control the servo?

1. When the load is moving
2. When the load is stationary
3. When the load is at or near the command position
4. When the load is far from the command position

1-65. The function of synchro switching networks in dual-speed systems is to

1. determine speed ratio between fine and coarse synchro
2. determine which system responds to null the error signal
3. produce error signals
4. turn the system on and off

1-66. How would a radar antenna likely react if its coarse and fine synchro receivers are not electrically zeroed together?

1. It would align with the coarse synchro electrical zero position and stop
2. It would align with the fine synchro electrical zero position and stop
3. It would not move
4. It would oscillate between the coarse and fine synchro's electrical zero positions

1-67. In a dual-speed synchro system, what is the electrical zero reference position for the fine synchro?

1. The axis of the rotor coil aligned with the axis of the S3 stator coil
2. The axis of the fine synchro rotor aligned with the axis of the S2 stator coil
3. The electrical zero position of the coarse synchro
4. The mechanical zero position of the coarse synchro

1-68. The purpose of the stickoff voltage in a servosystem is to prevent two electrical zero positions in which of the following synchros?

1. Coarse CT
2. Fine CT
3. Coarse CX
4. Fine CX

Assignment 2

Data Transmission, and Servomechanisms

Textbook Assignment: FTG 3 & 2, NAVEDTRA 10207-B; pages 2-15 through 3-6

Learning Objective: Describe resolvers with regard to construction, operation, application, compensation, booster amplifiers, zeroing, and maintenance.

2-1. What is the primary function of a resolver?

1. To resolve a vector quantity into sine and cosine components
2. To produce resultant vectors from two input components
3. Both 1 and 2 above
4. To resolve geometric variables

QUESTION 2-2 IS TO BE JUDGED TRUE OR FALSE.

2-2. A resolver is a variable transformer capable of both data transmission and mathematical computation involving trigonometry.

1. True
2. False

2-3. What angle describes the placement of the stator windings in most resolvers?

1. 0°
2. 45°
3. 90°
4. 120°

2-4. What is the input-to-output signal ratio of a resolver?

1. 1:1
2. 1:2
3. 2:1
4. 3:1

2-5. The inputs to a resolver can be described as

1. electrical only
2. mechanical only
3. both electrical and mechanical
4. angular rotation

2-6. Refer to figure 2-13B of the text. Assume that Ei is 200 volts. What is the value of Eo?

1. 8.66 volts
2. 17.32 volts
3. 86.6 volts
4. 173.2 volts

2-7. Which of the following windings are used when a resolver is used to resolve a single voltage into two (sine, cosine) components?

1. 1 rotor winding and 1 stator winding
2. 1 rotor winding and 2 stator windings
3. 2 rotor windings and 1 stator winding
4. 2 rotor windings and 2 stator windings

2-8. Refer to figure 2-15 of the text. The resultant flux field is produced by

1. the position of R1
2. the position of R2
3. E sin θ input voltage
4. both E sin θ and E cos θ input voltages

2-9. Which of the following is the purpose of the calibrating resistors in a resolver?

1. To compensate for voltage inaccuracies in the windings
2. To prevent phase shifts when the load changes
3. To standardize the electrical characteristics
4. Each of the above

2-10. In a resolver circuit, the compensators are connected in ______(a)______
(series, parallel) with the resolver coils
in order to regulate the resolver's ______(b)______ voltages.
(output, input)

1. (a) Series (b) output
2. (a) Series (b) input
3. (a) Parallel (b) output
4. (a) Parallel (b) input

2-11. What type of amplifier is the booster amplifier in a resolver circuit?

1. Power amplifier
2. Voltage amplifier
3. Current amplifier
4. Phase shift amplifier

2-12. Booster amplifiers function as voltage regulators because of what design characteristic?

1. Unity gain
2. Regenerative feedback
3. Negative feedback
4. Variable gain

2-13. The zero position of a resolver is determined by what angular relationship between a stator and its corresponding rotor?

1. Perpendicular
2. Acute
3. Parallel
4. Obtuse

2-14. When the corresponding stator and rotor of a resolver have an angular relationship of 90°, how much magnetic coupling exists between the two windings?

1. Maximum
2. 50%
3. 90%
4. None

2-15. The resolver coarse-zero test ensures that a proper phase relationship exists between what windings?

1. Rotor windings only
2. Stator windings only
3. Fine and coarse windings
4. Rotor and stator windings

2-16. Refer to figure 2-16A of the text. What condition is indicated if voltmeter V reads 20 volts when the rotor is set at course zero, and 18 volts when the input angle is increased counterclockwise?

1. The supply voltage is negative
2. The voltmeter leads are improperly connected
3. The coil at right angles to the energized stator coil is the cosine coil
4. The rotor has been zeroed in reverse phase

2-17. Refer to figure 2-16 of the text. When setting a resolver on (a) coarse zero, (b) fine zero, the voltmeter is connected across

1. (a) R4-S3, (b) R4-R2
2. (a) R4-S1, (b) R4-S1
3. (a) R2-S1, (b) R4-S3
4. (a) R2-S3, (b) R2-S3

2-18. Which of the following maintenance tasks for a resolver should be done on board ship?

1. Alignment tests and replacement of the resolver
2. Alignment tests and replacement of the internal bearings
3. Adjustment to the compensating circuits and replacement of compensating resistors
4. Adjustments to the compensating circuits and replacement of the resolver

Learning Objective: Describe the operation and construction of the step transmission system; and the operation of the balanced bridge circuits and the vernistat.

2-19. Step transmission systems are used in applications having which of the following requirements?

1. Precise angular position
2. Coarse angular position
3. Very low power handling capacity
4. Continuous position information

2-20. A step transmission system is desirable in many applications because it has which of the following characteristics?

1. Inexpensive
2. Rugged
3. Relatively powerful
4. Each of the above

2-21. Refer to figure 2-18 of the text. During operation of the step transmitter, which of the four contacts is in continuous contact with the shorting ring?

1. Contact 1
2. Contact 2
3. Contact 3
4. Contact C

2-22. The stator of a step motor has
___(a)___ coils angularly dis-
(quantity)
placed ___(b)___ degrees apart.
(quantity)

1. (a) 10 (b) 36
2. (a) 8 (b) 25
3. (a) 6 (b) 60
4. (a) 4 (b) 90

2-23. Refer to figure 2-19 and table 2-2 of the text. What will be the angular position of the rotor reference pole when contacts 1 and 2 are made and coils 1 and 1A are energized?

1. 0°
2. 15°
3. 30°
4. 60°

2-24. Refer to figure 2-18 of the text. What is the purpose of the diodes shown between the step transmitter and the step motor?

1. Spark suppressors
2. Voltage suppressors
3. Resistance suppressors
4. Current suppressors

2-25. Refer to figure 2-20 of the text. The balanced bridge circuit consists of two identical potentiometers connected in

1. parallel and ungrounded
2. parallel with a grounded centertap
3. series and ungrounded
4. series with a grounded centertap

2-26. In the balanced bridge circuit, what determines the amount and direction of the current flow?

1. The voltage applied to the wiper arms
2. The total resistance of the wiper arms
3. The potential difference between the wiper arms
4. The common voltage supply

2-27. A zero data signal is represented by which, if any, of the following positions of the potentiometers in a balanced bridge circuit?

1. High end of the potentiometer
2. Low end of the potentiometer
3. At ground potential
4. None of the above

2-28. A vernistat consists of a precision autotransformer with a potentiometer connected in what way?

1. In series with one end grounded
2. In parallel with one end grounded
3. In series with a grounded centertap
4. In parallel with a grounded centertap

2-29. A vernistat transmission system is more accurate than a balanced bridge system because the vernistat transmission has which of the following characteristics?

1. The entire reference voltage is sampled on each rotation of the potentiometer shaft
2. None of the reference voltage is sampled during a potentiometer shaft rotation
3. Only a percentage of the reference voltage is sampled on each rotation of the potentiometer shaft
4. It is more precisely calibrated

2-30. The vernistat potentiometer has
_____(a)_____ taps spaced
(what total number)
_____(b)_____ degrees
(a maximum of how many)
apart?

1. (a) 2 (b) 180
2. (a) 2 (b) 120
3. (a) 3 (b) 120
4. (a) 4 (b) 90

2-31. What total number of the vernistat potentiometer taps connected to the autotransformer are in use at any given time?

1. 1
2. 2
3. 3
4. 4

2-32. What total number of taps are on a vernistat autotransformer?

1. 31
2. 30
3. 29
4. 28

2-33. What is the gear ratio between the vernistat pinion gear and the autotransformer housing gear?

1. 30 to 31
2. 31 to 32
3. 29 to 28
4. 29 to 30

2-34. When a vernistat is configured to operate from zero to maximum, the output is taken between what two points?

1. The potentiometer wiper and the center tap of the transformer
2. One end of the potentiometer and the center tap of the transformer
3. One end of the potentiometer and one end of the transformer
4. The potentiometer wiper and one end of the transformer

Learning Objective: Identify the basic construction, functions, and operating principles of the different types of tachometer generators.

2-35. A tachometer generator transmits what information?

1. Velocity
2. Position
3. Speed
4. Range

2-36. Refer to figure 2-27 of the text. The voltage produced by the response tach has what relationship to the signal tach voltage?

1. Aids
2. Opposes
3. Leads
4. Lags

2-37. The reference a.c. source is applied to what winding of an a.c. tachometer?

1. Primary stator winding
2. Secondary stator winding
3. Magnetic core winding
4. Rotor winding

TO ANSWER QUESTIONS 2-38 THROUGH 2-40, SELECT FROM COLUMN B THE CHARACTERISTIC OF THE OUTPUT VOLTAGE FROM AN A.C. TACH THAT IS CONTROLLED BY THE INPUT TO THE A.C. TACH IN COLUMN A.

	A. INPUTS	B. CHARACTERISTICS
2-38.	The angular velocity of the rotor	1. Polarity
		2. Phase
2-39.	The rotation direction of the rotor	3. Frequency
2-40.	The cycle rate of the supply voltage	4. Amplitude

QUESTION 2-41 IS TO BE JUDGED TRUE OR FALSE.

2-41. The d.c. tach is basically a d.c. generator with permanent magnets to create the magnetic lines of force.

1. True
2. False

2-42. When compared to the a.c. tach system, the d.c. tach system has which of the following advantages?

1. It is more accurate
2. It uses less power
3. It changes speed more easily and has greater range
4. It requires more feedback

2-43. Refer to figure 2-29 of the text. What controls the speed and direction of rotation of the d.c. motor?

1. Control potentiometer wiper-arm position
2. Design characteristics of the motor
3. The signal voltage
4. The error voltage

2-44. Refer to figure 2-29 of the text. What property of the d.c. signal tach voltage(es) determines the direction of train motion?

1. Magnitude
2. Polarity
3. Rate of change of the magnitude
4. Rate of change of the polarity

2-45. Refer to figure 2-29 of the text. What is the purpose of the response tach?

1. To measure the director train rate
2. To determine the direction of train motion
3. To determine the amount of elevation movement
4. To measure the amount of train motion

Learning Objective: Identify the components of a fire control switchboard and the functions it performs as a part of a data transmission system.

2-46. What is the primary function of a fire control switchboard in a data transmission system?

1. Transmits data
2. Stores data
3. Controls data transmission
4. Switches data from one format to another

2-47. In figure 2-30 of the textbook, (a) how are the signal sources of directors 1 and 2 connected to the switchboard, and (b) how is the computer electrically connected to either of the two directors at the switchboard?

1. (a) In parallel (b) in parallel
2. (a) In parallel (b) in series
3. (a) In series (b) in parallel
4. (a) In series (b) in series

2-48. Which of the following functions is/are performed by an ACO switch?

1. Isolates components of a FC system
2. Acts as an impedance matching device
3. Both 1 and 2 above
4. Automatically controls the output of the switchboard

2-49. Where is the ACO switchboard for a gun fire control system Mk 56 normally located on board ship?

1. IC room
2. Plotting room
3. GFCS Mk 56 director
4. GFCS Mk 56 control room

2-50. In which of the following switching applications would a manually operated JR switch be appropriate?

1. Remote
2. Local
3. Frequent
4. Infrequent

QUESTION 2-51 IS TO BE JUDGED TRUE OR FALSE.

2-51. The AJR switch is normally used in applications requiring infrequent switching.

1. True
2. False

2-52. In which of the following circuit types would a snap switch be more appropriate than a JR type switching device?

1. Low-current
2. High-current
3. Low-impedance
4. High-impedance

Learning Objective: Identify the basic operating characteristics and functions of a servomechanism.

IN ANSWERING QUESTIONS 2-53 THROUGH 2-55, REFER TO FIGURE 3-2 OF THE TEXT.

TO ANSWER QUESTIONS 2-53 THROUGH 2-55, SELECT FROM COLUMN B THE SIGNAL THAT IS REPRESENTED BY THE CONDITION IN COLUMN A.

	A. CONDITIONS	B. SIGNALS
2-53.	The desired position of the load	1. Output signal
2-54.	The reaction of the servo to the desired position of the load in relationship to the actual position of the load	2. Error signal 3. Feedback (response) signal 4. Input signal
2-55.	The difference between the desired position and the actual position of the load	

2-56. Which of the following is characteristic of a servo?

1. It is a control device
2. It is a power amplifier
3. It is an entire system
4. It has all of the above characteristics

2-57. The minimum components necessary in a servo system are an error detector and what other component(s)?

1. Power amplifier
2. Feedback line
3. Both 1 and 2 above
4. Power amplifier and error reducer

Learning Objective: Identify the different types and operating principles of servomechanism error detectors.

2-58. Which of the following operations is a function of a servosystem error detector?

1. To compute the algebraic sum of the order and feedback signals
2. To compute the algebraic sum of the order and error signals
3. To multiply the order signal by the error signal
4. To multiply the order signal by the feedback signal

2-59. By what means is the error signal transmitted in the servoamplifier?

1. Hydraulically
2. Electrically
3. Mechanically
4. Electromechanically

2-60. How is the input (order) signal applied in a CT error detector?

1. It mechanically positions the CX rotor
2. It mechanically positions the CT rotor
3. It is applied electrically to the CX rotor
4. It is applied electrically to the CX stator

2-61. What causes the rotor of the CT in a CT error detector to drive to its null position?

1. Electrical output of the CX stator
2. Mechanical position of the CX rotor
3. Electrical feedback from the error reducer
4. Mechanical feedback from the error reducer

2-62. Refer to figure 3-5 of the text. What section of the servo system shown represents the closed loop?

1. Error detector
2. Feedback line
3. Error signal
4. Power amplifier

2-63. By what means is the error voltage computed in a balanced potentiometer error detector?

1. The difference is taken between the voltages across R1 and R2
2. The voltages across R1 and R2 are summed
3. Ei and Eo are summed
4. The difference is taken between Ei and Eo

2-64. By what means are the input and feedback signals transmitted in a summing network error detector?

1. Both electrically
2. Input mechanically, feedback electrically
3. Both mechanically
4. Input electrically, feedback mechanically

2-65. When there are two or more order signals, to what is the servo output proportional?

1. The algebraic sum of the order signals
2. The algebraic difference of the order signals
3. The sum of the order and feedback signals
4. The difference between the order and feedback signals

Learning Objective: Identify the basic functions and operating principles of servo amplifiers and error reducers.

2-66. Which of the following characteristics is a basic function of servoamplifiers?

1. Amplified error signal
2. Stable operation
3. Fast response time
4. All of the above

2-67. Which of the following characteristics is a disadvantage of d.c. servoamplifiers?

1. High drift rate
2. Slow response time
3. Limited frequency range
4. Limited power range

2-68. What type of gain versus frequency response is desirable in a servoamplifier?

1. Flat
2. Minimum
3. Inverse
4. Distortionless

2-69. What component of a servosystem drives the load to its ordered position?

1. Error detector
2. Error reducer
3. Servoamplifier
4. Power amplifier

2-70. Which of the following characteristics of hydraulic power devices make them desirable in fire control applications?

1. Fast response time
2. Accuracy
3. High power capability
4. All of the above

Assignment 3

Servomechanisms

Textbook Assignment: FTG 3 & 2, NAVEDTRA 10207-B; pages 3-6 through 3-22

Learning Objective: Identify the operating characteristics of electric, electromechanical, and electrohydraulic servosystems.

3-1. What primary factor determines the type of servo to be used in a given application?

1. The power source
2. The load
3. The ease of repair
4. The operating life expectancy

3-2. What type of servosystem would be used to control a large antenna that is subjected to sudden and drastic changes in training and elevating?

1. Electromechanical
2. Electrohydraulic
3. Electrical
4. Amplidyne

REFER TO FIGURE 3-7 OF THE TEXT IN ANSWERING QUESTIONS 3-3 THROUGH 3-7.

3-3. What causes the rotor shaft of the synchro receiver to turn?

1. Order signal
2. Error signal
3. Feedback signal
4. Supply voltage

3-4. What part of the synchro receiver is driven by a servomotor?

1. The rotor
2. The mechanical input shaft
3. The contact arm
4. The stator

3-5. What, if any, is the effect on the operation of an electric servo if one of the contacts breaks off?

1. The servo will not drive in either direction
2. The servo will drive in only one direction
3. The servo will drive continuously
4. No effect, normal operation will continue

3-6. What, if any, is the effect on the operation of an electric servo if the rotor contact arm breaks off?

1. The servo will not drive in either direction
2. The servo will drive in only one direction
3. The servo will drive continuously
4. No effect, normal operation will continue

3-7. What is the purpose of the capacitor across the servomotor contacts?

1. Isolation of supply voltage
2. Impedance matching
3. Phase shift supply voltage
4. Block d.c. voltage

3-8. Electric servos in FC systems are used for which of the following functions?

1. Position control of light loads
2. Position control of heavy loads
3. Precision control of light loads
4. Precision control of heavy loads

REFER TO FIGURE 3-9 OF THE TEXT IN ANSWERING QUESTIONS 3-9 THROUGH 3-11.

TO ANSWER QUESTIONS 3-9 THROUGH 3-11, SELECT FROM COLUMN B THE COMPONENT THAT PERFORMS THE FUNCTION AS LISTED IN COLUMN A.

A. FUNCTIONS	B. COMPONENTS
3-9. Error detector	1. Range mechanism
3-10. Error reducer	2. Control transformer (CT)
3-11. Load	3. Servomotor
	4. Control transmitter (CX)

3-12. The primary function of the amplifier in a servosystem is to strengthen the

1. input signal
2. error signal
3. response signal
4. reference voltage to the feedback rate generator

REFER TO FIGURE 3-10 OF THE TEXT IN ANSWERING QUESTIONS 3-13 THROUGH 3-19.

3-13. The output of the electromechanical servo section of the electrohydraulic servo becomes the

1. input to the hydraulic-mechanical servo section
2. prime mover of the radar antenna
3. prime mover of the hydraulic pump
4. response for the electrohydraulic servo

TO ANSWER QUESTIONS 3-14 THROUGH 3-16, SELECT FROM COLUMN B THE SERVO FUNCTION THAT IS PERFORMED BY THE COMPONENT LISTED IN COLUMN A.

A. COMPONENTS	B. FUNCTIONS
3-14. Differential linkage and servovalve	1. Amplifier 2. Error Reducer
3-15. Hydraulic pump	3. Error Detector
3-16. Cylinder	4. Response

3-17. What type of signals compose the order, response, and error signals to and from the error detector of the electromechanical servo loop?

1. Both order and error signals—electrical, and response signal—mechanical
2. Both order and response signals—mechanical, and error signal—electrical
3. All three signals electrical
4. All three signals mechanical

3-18. What type of signals are the order, response, and error signals to and from the error detector of the hydraulic-mechanical servo loop?

1. Both order and error signals—hydraulic and response signal—mechanical
2. Both order and response signals—mechanical, and error signal—hydraulic
3. All three signals hydraulic
4. All three signals mechanical

3-19. Trace the energy conversion through the electrohydraulic servo starting with the gun sight position order signal and ending with the feedback signal that cancels the order signal.

1. Electrical → hydraulic → mechanical → electrical → mechanical
2. Electrical → mechanical → hydraulic → electrical mechanical
3. Electrical → hydraulic → electrical → mechanical → electrical
4. Electrical → mechanical → hydraulic → mechanical → electrical

Learning Objective: Identify the characteristics of position, velocity and acceleration order signals and the operating principles of position and velocity servos.

3-20. Which of the following types of order signals are used to determine the response of a servo?

1. Position
2. Velocity
3. Acceleration
4. Each of the above

3-21. Which of the following components may be used as error detectors in position servos?

1. Resistors, capacitors, and transformers
2. Synchros, resolvers, and balanced bridge circuits
3. Synchros, resolvers, and amplifiers
4. Resistors, capacitors, and synchros

3-22. What type of servo uses an error signal that represents a displacement?

1. Position
2. Velocity
3. Acceleration
4. Rate

Learning Objective: Identify the characteristics and operating principles of servo sensors and synchronization circuits.

3-23. Which of the following devices can be used to convert the input and output of servos into usable form?

1. Synchronizer
2. Modulator
3. Sensor
4. Resolver

3-24. The output of a velocity servo system that is changing speed is proportional to which of the following signals?

1. An acceleration signal
2. A direction signal
3. A position signal
4. A velocity signal

3-25. Which of the following features is an advantage of the dual-speed data transmission system over a single speed system?

1. Smaller size
2. Ambiguous synchronization
3. Greater accuracy
4. Larger angle of rotation

3-26. Which of the following combinations usually represents the ratio between the fine and coarse gears in a dual-speed (two-speed) synchro transmission system?

1. 1:1
2. 18:1
3. 36:1
4. 72:1

3-27. In a dual-speed synchro system, which of the following choices best describes the condition(s) under which the fine signal has control?

1. When the load is moving
2. When the load is stationary
3. When the load is at or near synchronization
4. When the load is far from synchronization

REFER TO FIGURE 3-12 OF THE TEXT IN ANSWERING QUESTIONS 3-28 AND 3-29.

3-28. Assume that the synchro system connected to the circuit has a synchronizing error of approximately 15°. What effect will the error have on the impedance of (a) the rectifier network CR3, CR4, CR5, and CR6 in the coarse signal circuit and (b) the rectifier network CR1 and CR2 in the fine signal circuit?

1. (a) Acts as a high impedance; (b) acts as a low impedance
2. (a) Acts as a low impedance; (b) acts as a high impedance
3. Both (a) and (b) act as high impedances
4. Both (a) and (b) act as low impedances

3-29. For small errors, the fine signal is applied to the amplifier input and most of the coarse signal is dropped across

1. resistor R1
2. the diode network in the coarse signal circuit
3. the diode network and resistor R1
4. resistor R1 and the summing network

Learning Objective: Identify the types and operating principles of modulators and demodulators used in fire control servos.

3-30. What is the purpose of the modulator in a servo system?

1. To rectify the a.c. error signal and convert it to a pulsating d.c. error voltage
2. To increase the amplitude of the error signal
3. To convert the d.c. error signal voltage to an a.c. error voltage
4. To convert a high-frequency a.c. signal to a low-frequency a.c. signal

USE THE FOLLOWING CHOICES FOR QUESTIONS 3-31 THROUGH 3-33 CONCERNING MODULATION:

1. MAGNITUDE OF THE A.C. REFERENCE VOLTAGE
2. MAGNITUDE OF THE D.C. ERROR VOLTAGE
3. FREQUENCY OF THE A.C. REFERENCE VOLTAGE
4. POLARITY OF THE D.C. ERROR VOLTAGE

3-31. The phase of the error signal is controlled by the

3-32. The magnitude of the a.c. error signal is governed by the

3-33. The synchronous control elements are operated by the

3-34. At what frequencies are electromechanical modulators usually operated?

1. 30 or 60 hertz
2. 60 or 120 hertz
3. 60 or 400 hertz
4. 120 or 400 hertz

REFER TO FIGURE 3-13 OF THE TEXT IN ANSWERING QUESTIONS 3-35 AND 3-36.

3-35. Which crystal diode conducts current when both the a.c. reference and the d.c. error signals are positive?

1. CR1
2. CR2
3. CR3
4. CR4

3-36. What is the frequency of the current through the primary of T1?

1. 60 H_z
2. 400 H_z
3. Difference between error voltage and reference voltage frequencies
4. Same as the a.c. reference voltage frequency

3-37. The conversion of a.c. error signals to d.c. error signals is known as

1. amplifying the signal
2. demodulating the signal
3. modulating the signal
4. rectifying the signal

QUESTION 3-38 IS TO BE JUDGED TRUE OR FALSE.

3-38. A discriminator is unsuitable for use as a servo demodulator because it is not capable of detecting both phase and magnitude of an a.c. signal.

1. True
2. False

REFER TO FIGURE 3-14 OF THE TEXT IN ANSWERING QUESTIONS 3-39 THROUGH 3-41.

3-39. What will be the d.c. output when only the reference voltage is supplied?

1. Equal to and in phase with the reference voltage
2. Equal to but out of phase with the reference voltage
3. Zero volts
4. 115 volts

3-40. Which of the following statements correctly describes the phase relationship between the reference voltage on the plates of the two diodes?

1. The voltages are always in phase
2. The voltages are always out of phase
3. The voltages may be in or out of phase, depending on the output from T1
4. The voltages may be in or out of phase, depending on the output from T2

3-41. Which of the following statements describes the conduction of the two diodes?

1. The diodes always conduct equally
2. The diodes always conduct unequally
3. The diodes conduct equally or unequally, depending on the output of T1
4. The diodes conduct equally or unequally, depending on the output of T2

Learning Objective: Identify the types, advantages, and unique circuits of servoamplifiers.

3-42. Which of the following characteristics is an inherent advantage of a servoamplifier?

1. Low output impedance
2. Low noise level
3. Small and fixed phase-shift of the output with respect to the input
4. Each of the above

3-43. What component is incorporated into some servosystems to ensure that signal characteristics are within the requirements of the amplifier?

1. Modulator
2. Demodulator
3. Preamplifier
4. Error detector

REFER TO FIGURE 3-15 OF THE TEXT IN ANSWERING QUESTIONS 3-44 THROUGH 3-48.

TO ANSWER QUESTIONS 3-44 THROUGH 3-46, SELECT FROM COLUMN B THE SUPPLY VOLTAGE FOR THE CIRCUIT THAT PERFORMS THE FUNCTION DESCRIBED IN COLUMN A.

	A. FUNCTION	B. SUPPLY VOLTAGE
3-44.	To provide collector supply for transistors Q1 and Q2	1. 1 V d.c. 2. 18 V d.c.
3-45.	To provide collector supply for transistors Q3 and Q4	3. 30 V d.c. 4. 48 V d.c.
3-46.	To provide regulation control for the fixed base-emitter bias	

3-47. CR2 will conduct when what condition exists?

1. The coarse error signal is larger than the signal determined by the synchronizing circuit
2. The coarse error signal is smaller than the signal determined by the synchronizing circuit
3. When feedback from the tachometer generator is larger than the signal determined by the synchronizing circuit
4. When feedback from the tachometer generator is smaller than the signal determined by the synchronizing circuit

3-48. What is the a.c. source for the power supplies of the collectors?

1. Ship lighting supply
2. Synchro system supply
3. Fire control system 115 volt supply
4. Fire control system 440 volt supply

Learning Objective: Identify the differences between a.c. and d.c. servomotors; the adjustment procedures applicable to servoamplifiers, and the effects and methods of damping.

3-49. The turning force in a two-phase induction motor is obtained by means of

1. two rotating magnetic fields that induce voltages in the rotor windings
2. a magnetic field produced from two stationary fields 90° out of phase
3. a magnetic field produced from two stationary fields 180° out of phase
4. two coils on opposite sides of the rotor whose fields add to produce a rotating magnetic field

3-50. The direction of rotation of an a.c. servomotor can be reversed bv

1. reversing the phase relationship between the stator windings
2. reversing the motor armature current
3. reducing the phase relationship between the stator windings
4. varying the amplitude of the voltage to one of the motor's stator windings

3-51. Which type of servomotor is most suitable for use as director train drive motor?

1. A.C. split-phase induction servomotor
2. A.C. two-phase induction servomotor
3. D.C. shunt field servomotor
4. D.C. permanent magnet servomotor

3-52. Drift in a d.c. servoamplifier may be caused by which of the following effects?

1. Aging effects of components
2. Humidity effects on components
3. Changes in power supply voltages
4. All of the above

3-53. Which of the following servo components receives and compares the ordered position and the actual position of the servo's output?

1. Amplifier
2. Error reducer
3. Error detector
4. Servomotor

3-54. What condition of a servo loop determines the size of the error signal required to drive the servomotor?

1. The gain of the amplifier
2. The efficiency of the error reducer
3. The accuracy of the error detector
4. The reaction time of the response drive

3-55. What condition of a servo loop determines the amount of control current required to cause the servomotor to drive?

1. The gain of the amplifier
2. The efficiency of the error reducer
3. The accuracy of the error detector
4. The reaction time of the response drive

3-56. What is the angular displacement between the input and output of a servo under static conditions called?

1. System accuracy
2. Dynamic accuracy
3. Static accuracy
4. Signal accuracy

TO ANSWER QUESTIONS 3-57 THROUGH 3-59, SELECT FROM COLUMN B THE ADJUSTMENT THAT PERFORMS THE FUNCTION LISTED IN COLUMN A.

	A. FUNCTIONS	B. ADJUSTMENTS
3-57.	Controls the size of the signal voltage	1. Balance 2. Phase
3-58.	Eliminates creep when using a push-pull amplifier	3. Damping 4. Gain
3-59.	Controls the sensitivity of the system	

3-60. What determines the optimum gain setting of a servomechanism system?

1. Degree of system stability
2. Amount of velocity error allowable
3. Desired speed of response
4. Torque requirement of the output

3-61. A "tight" servo would NOT be practical as a control system for fire control for which of the following reasons?

1. It is unstable
2. It has a tendency to overshoot
3. It has a tendency to oscillate
4. It may be impractical for any of the above reasons

3-62. The principal function of damping in a servomotor system is to

1. reduce the noise level
2. prevent overloading the circuit
3. eliminate the load oscillations
4. lessen the amplitude and duration of the load oscillations

3-63. Servos having which of the following characteristics would take an excessively long time to synchronize and would have a large steady-state error?

1. Overdamped
2. Underdamped
3. "Tight"
4. "Hunting"

3-64. Which form of damping absorbs the greatest amount of power from the servosystem?

1. Friction clutch damping
2. Magnetic clutch damping
3. Pure viscous damping
4. Error-rate damping

3-65. What physical property makes the flywheel an effective damping device?

1. Inertia
2. Velocity
3. Structure
4. Acceleration

3-66. What device is used to govern the amount of power a flywheel will draw from a motor?

1. Amplifier
2. Friction clutch
3. Error detector
4. Saturable reactor

3-67. Which form of damping provides coupling between the flywheel and the servomotor output shaft by the use of eddy currents?

1. Friction clutch damping
2. Magnetic clutch damping
3. Pure viscous damping
4. Error-rate damping

3-68. The error-rate voltage combined with the error signal in a servosystem is used to

1. compensate for losses in the system
2. determine the direction of rotation of the servomotor
3. reduce the amplification in the system
4. reduce overshooting and oscillation in the system

3-69. What disadvantage of viscous damping may be reduced by the use of error-rate damping?

1. Excessive transient oscillation
2. Long transit time
3. Steady-state error
4. Tendency to overshoot

3-70. The amplitude of the output voltage of a tachometer generator is determined by the

1. direction of rotation of the servomotor
2. speed of rotation of the servomotor
3. frequency of the a.c. reference voltage
4. amplitude of the a.c. reference voltage

3-71. What type of circuit is an integrator?

1. Delay network
2. Inductive input filter
3. Bridge rectifier
4. Resistive-capacitive coupling network

REFER TO FIGURE 3-19 OF THE TEXT IN ANSWERING ITEMS 3-72 AND 3-73.

3-72. Which of the following operations must be performed on an a.c. error signal before it enters the network?

1. Modulated
2. Amplified
3. Phase-shifted
4. Demodulated

3-73. What is the purpose of the capacitor in the integration circuit?

1. To decrease the error signal
2. To increase the error signal
3. To assist the servo to attain proper speed
4. To demodulate an a.c. signal

3-74. What part(s) of a velocity servosystem determines the amount of lag in the servo's output velocity?

1. Amplifier
2. Computer
3. Rate generators
4. Error signal

3-75. What type of circuit is used to reduce velocity lag in a servo having a very high velocity?

1. Integrator
2. Differentiator
3. Compensator
4. Modulator

Assignment 4

Gyroscopes and The Gun Fire Control Problem

Textbook Assignment: FTG 3 & 2, NAVEDTRA 10207-B; pages 4-1 through 5-6

Learning Objective: Identify the properties of a basic gyroscope.

4-1. Any rapidly spinning body has characteristics similar to those of

1. an accelerometer
2. a gyroscope
3. an arrow in flight
4. a submerged body

4-2. What is the primary function of gyros in the fire control system?

1. Stabilization
2. Coordinate conversion
3. Angular computations
4. Rate computations

4-3. The spin axis of a gyroscope tends to remain fixed in a given direction if the rotor

1. is parallel to the Earth's surface
2. has no force applied to it
3. is perpendicular to the Earth's surface
4. has a large diameter

4-4. What property of a gyroscope causes it to attempt to maintain a spin axis that is fixed in space?

1. Precession
2. Rigidity
3. Stabilization
4. Translation

4-5. In relationship to an applied force, a gyroscope rotor precesses in what direction?

1. Parallel
2. Vertical
3. Horizontal
4. Perpendicular

IN ANSWERING QUESTIONS 4-6 AND 4-7, REFER TO FIGURE 4-3A OF THE TEXT.

4-6. The spin axis of the gyro wheel is represented by which of the following axes?

1. X-X axis
2. Y-Y axis
3. Z-Z axis
4. X-X and Y-Y axes

4-7. A downward force applied to point A would cause precession about which of the following axes?

1. Y-Y axis
2. Z-Z axis
3. X-X axis
4. X-Z axis

IN ANSWERING QUESTION 4-8, REFER TO FIGURE 4-3B OF THE TEXT.

4-8. What would happen if the gyro continued precessing in the direction shown?

1. Precession would continue until the spin axis was once more vertical
2. Precession would stop when the spin axis was parallel to the Z-Z axis
3. Precession would continue until the spin axis was perpendicular to the Y-Y axis
4. Precession would stop when the spin axis was horizontal

4-9. What will happen when the force causing a gyro to precess is removed?

1. Precession stops immediately
2. The gyro rotor returns to its original plane of rotation
3. Precession continues
4. Precession gradually slows down and stops

Learning Objective: Identify the basic elements of, and the forces that affect gyros, and the means of compensating for the effects of those forces.

IN ANSWERING QUESTION 4-10, REFER TO FIGURE 4-5 OF THE TEXT.

4-10. Along which of the following axes of the gyro does precession occur?

1. Output axis
2. Input axis
3. Spin axis
4. All of the above axes

4-11. In what total number of planes does a universally mounted gyro have freedom of movement?

1. One
2. Two
3. Three
4. Four

4-12. Assume that a spinning gyro is placed at the equator with its spin axis horizontal to the Earth. After six hours, what relationship to the Earth will the spin axis have?

1. Vertical
2. Horizontal
3. 45° angle
4. 60° angle

4-13. What is the cause of apparent gyro precession?

1. Variations in the Earth's magnetic field
2. Rotation of the Earth
3. Imbalance in the gyro rotor
4. Friction on the rotor shaft bearings

4-14. Which of the following defects in gyros causes unwanted gyro precession?

1. Imbalance in the gyro rotor
2. Asymmetrical friction of the rotor shaft bearings
3. Friction in the gimbal bearings
4. Each of the above

4-15. What is the purpose of the gyro-erection system in a direction-indicating gyro?

1. To maintain the gimbal in an erect position
2. To correct for the effects of apparent and mechanical drift
3. To lock the gyro in a fixed position
4. To compensate for the effects of gravity on rotor spin

4-16. When is the gyro-erection system needed in a direction-indicating gyro?

1. When its rotor has been spinning only
2. When the gyro is operating only
3. When the gyro is secured
4. When its rotor has been set spinning and the gyro is operating

4-17. Which of the following types of force may be used in a gyro erection system to effect the desired precession?

1. Electrical
2. Pneumatic
3. Mechanical
4. Each of the above forces

4-18. Viewed from above the North Pole, what is the rate and direction of the Earth's rotation?

1. 15° an hour clockwise
2. 15° an hour counterclockwise
3. 30° an hour clockwise
4. 30° an hour counterclockwise

4-19. In which direction is the latitude correction weight applied in a direction-indicating gyro?

1. East
2. West
3. North
4. South

4-20. Consider the effect of the Earth's rotation on a gyro at the Equator. What would be the effect, if any, of the Earth's rotation on a gyro with a vertical spin axis if it were placed at the North or South Pole?

1. No effect
2. Reverse of the effect
3. The same effect
4. Much greater effect

4-21. On a gyro that is at an intermediate North latitude, what must be done to the latitude correction weight to compensate for the effects of the Earth's rotation?

1. The amount of weight must be increased
2. The amount of weight must be decreased
3. The weight must be moved toward the spin axis
4. The weight must be moved away from the spin axis

Learning Objective: Identify the basic applications of gyros.

4-22. What type of gyro is used to indicate directions from a desired bearing?

1. Restrained
2. Directional
3. Stabilizing
4. Rate

4-23. Why must a bearing-indicating gyro be leveled and set the desired heading periodically?

1. It has no compensation for rotation of the Earth
2. It has mechanical instability of internal components
3. It has unavoidable friction of the moving components
4. It has inherent slight rotor imbalance

4-24. What type of gyro is used to establish a fixed horizontal reference plane?

1. Restrained
2. Directional
3. Stabilizing
4. Rate

4-25. Which of the following planes is the stabilized reference frame used in the solution of the fire control problem?

1. Deck and normal
2. Deck and vertical
3. Horizontal and vertical
4. Horizontal and normal

4-26. Which of the following planes is the unstabilized reference frame used in the solution of the fire control problem?

1. Deck and normal
2. Deck and vertical
3. Horizontal and vertical
4. Horizontal and normal

4-27. The motion of the ship's bow as it rises and falls is called

1. crosslevel
2. level
3. pitch
4. roll

4-28. The angle between the vertical and normal planes with its vertex at the ship's centerline measures which of the following stabilization angles?

1. Degree of crosslevel
2. Degree of level
3. Degree of pitch
4. Degree of roll

4-29. If the bow of a ship rises above the horizon at the same time the port side dips below the horizon, which of the following conditions exist?

1. Positive pitch and positive roll
2. Negative pitch and negative roll
3. Positive pitch and negative roll
4. Negative pitch and positive roll

4-30. Tilt across the line of sight is measured by the quantity called

1. angle of roll
2. angle of pitch
3. crosslevel angle
4. level angle

4-31. Which of the following gyros is a single-degree-of-freedom gyro?

1. Universally mounted
2. Directional
3. Rate
4. Stabilizing

4-32. In a rate gyro, the rate-of-turn determines the amount of

1. translation
2. spin velocity
3. precession
4. compensation

Learning Objective: Identify the operating principles and components of a basic stable element.

4-33. The primary purpose of a stable element is to measure what quantity?

1. Deviation of deck plane from horizontal plane
2. Deviation of normal plane from the deck plane
3. Pitch and roll rate of change
4. Level and crosslevel rate of change

4-34. What is the purpose of the torsion wires in a flotation type of stable element gyro?

1. Provide electrical input
2. Provide electrical output
3. Support the gyro case
4. Hold the gyro in a fixed position

IN ANSWERING QUESTIONS 4-35 AND 4-36, REFER TO FIGURE 4-15 OF THE TEXT.

4-35. When the gyro has its spin axis centered through the top-to-bottom reference line of the flotation tank, how much output is available from the pick-up coils?

1. No output is available
2. Maximum output is available
3. Fifty percent of maximum output is available
4. Seventy-five percent of maximum output is available

4-36. The output of the element is proportional to the

1. angle between the gyro spin axis and the gimbal ring
2. input torque on the torsion wires
3. angle between the gyro spin axis and the tank reference line
4. velocity of the gyro rotor

4-37. What is the purpose of the stable gyro gimbals?

1. To restrain the gyro
2. To maintain gyro in the vertical plane
3. To prevent apparent precession
4. To maintain the gyro at a constant spin velocity

IN ANSWERING QUESTION 4-38, REFER TO FIGURE 4-16 OF THE TEXT.

4-38. What gimbal is mounted to the frame of the stable element?

1. Director train
2. Level
3. Aximuth
4. Crosslevel

4-39. The director train gimbal is always aligned with the

1. vertical plane
2. horizontal plane
3. line-of-sight bearing
4. ship's true bearing

4-40. The crosslevel gimbal is mounted upon which of the following gimbals?

1. Director train
2. Level
3. Azimuth
4. Director elevation

4-41. Which of the following gimbals measures the tilt of the deck plane in the line of sight?

1. Director train
2. Level
3. Crosslevel
4. Azimuth

4-42. Which of the following gimbals holds the stable element gyro?

1. Director train
2. Level
3. Crosslevel
4. Azimuth

QUESTION 4-43 IS TO BE JUDGED TRUE OR FALSE.

4-43. The azimuth gimbal in a stable element keeps the gyro pointing along the line of sight.

1. True
2. False

4-44. What type of force acts upon a pendulum to cause it to provide a useful output?

1. Electrical
2. Mechanical
3. Gravitational
4. Magnetic

4-45. In what total number of planes is a stable element pendulum free to move?

1. One
2. Two
3. Three
4. Four

4-46. The electrical signals produced by the stable element pendulums are used to drive which of the following gimbals?

1. Director train and level
2. Level and crosslevel
3. Crosslevel and azimuth
4. Azimuth and director train

4-47. The two pendulums mounted on the azimuth gimbal have what angular relationship?

1. 30° apart
2. 45° apart
3. 90° apart
4. 180° apart

QUESTION 4-48 IS TO BE JUDGED TRUE OR FALSE.

4-48. During the erection process the movement of the gimbals causes the torsion wires in the gyro suspension system to become twisted and exert torque on the gyro, causing it to precess in a decreasing spiral until it is aligned with the vertical plane.

1. True
2. False

4-49. Which of the following pendulums remains active after the gyro spin axis has reached the vertical plane?

1. Azimuth
2. Director train
3. Level
4. Cross level

4-50. The latitude correction signal is applied to which of the following stable element signal circuits?

1. East-west azimuth pendulum
2. North-south level pendulum
3. North-south azimuth pendulum
4. East-west level pendulum

Learning Objective: Identify the basic elements of interior and exterior ballistics, and the forces that govern the movement of projectiles in a vacuum.

4-51. The curved path followed by a projectile in its flight from gun to first impact is called a

1. ballistic
2. trajectory
3. controlled flight
4. pattern

4-52. The initial velocity of a projectile is governed by the condition of which of the following components?

1. The gun
2. The projectile
3. The propelling charge
4. All of the above

4-53. After the projectile and powder charge have been loaded into the gun it is sealed by the

1. breech mechanism
2. projectile's nose
3. projectile's rotating band
4. gun bore rifling

4-54. The rifling of a gun bore causes the projectile, while in flight, to

1. spin
2. tumble
3. maintain a straight course
4. maintain a curved course

4-55. A spinning projectile causes its trajectory to be

1. curved
2. straight
3. predictable
4. unpredictable

4-56. You are inspecting a 5-inch gun for effects of erosion after a three month period of fairly consistent firing. Which of the following parts will show the greatest amount of wear?

1. Lands
2. Grooves
3. Breech opening
4. Muzzle opening

4-57. In ballistics, the direction along which the projectile leaves the gun is known as the

1. line of extension
2. gun axis line
3. line of fire
4. ballistics line

4-58. Two factors of exterior ballistics that are always present are the effects of

1. bore erosion and propelling charge
2. air and gravity
3. type of projectile and air
4. gravity and bore erosion

4-59. A free-moving object in outer space has which of the following properties?

1. Zero acceleration
2. Zero inertia
3. Decreasing velocity
4. Decreasing weight

4-60. An object moving through a vacuum on earth is unlike one moving through outer space in that it has

1. velocity
2. inertia
3. mass
4. weight

4-61. The amount a gun is elevated above the horizontal is called the

1. angle of projection
2. striking angle
3. angle of departure
4. fall angle

4-62. The percentage of projectile momentum contained in the horizontal (Uh) and vertical (Uv) components is a function of which of the following angles?

1. Angle of departure
2. Striking angle
3. Angle of fall
4. Angle of projection

4-63. The highest point in the trajectory of a projectile is known as the

1. gravitational change point
2. maximum ordinate
3. maximum velocity point
4. deviation ordinate

4-64. In a vacuum trajectory, which of the following angles are equal?

1. Departure and striking
2. Projection and fall
3. Departure and fall
4. Projection and departure

USE THE FOLLOWING ALTERNATIVES FOR QUESTIONS 4-65 THROUGH 4-68 WHICH ARE ANGLES OF DEPARTURE FOR A GUN FIRED IN A VACUUM.

1. 0° only
2. 45° only
3. 90° only
4. 0° or 90°

4-65. The shortest horizontal component (Uh) will be obtained by an angle of

4-66. The longest horizontal component (Uh) will be obtained by an angle of

4-67. The shortest horizontal range will be obtained by an angle of

4-68. The longest horizontal range will be obtained by an angle of

4-69. In which of the following firing situations is high angle fire most important?

1. AA fire
2. Surface fire
3. Gunfire support enfilade fire
4. Precaution calibration for surface fire

4-70. Approximately how far along the line of flight of a shell from the gun to the point of impact is the high point of a vacuum trajectory?

1. 1/3 of the distance
2. 1/2 of the distance
3. 2/3 of the distance
4. 3/4 of the distance

4-71. Which of the following is a characteristic of a vacuum trajectory in Earth's gravity field?

1. The projectile travels a symmetrical curve
2. The angle of fall equals angle of departure
3. The striking velocity equals initial velocity
4. Each of the above

Assignment 5

The Gunfire Control Problem

Textbook Assignment: FTG 3 & 2, NAVEDTRA 10207-B; pages 5-6 through 5-28

Learning Objective: Identify the elements of exterior ballistics and the forces affecting a projectile's trajectory in air.

5-1. Which of the following aspects of exterior ballistics has a large variation when the shot is through air rather than in a vacuum?

1. Trajectory
2. Initial velocity
3. Gravity compensation
4. Line of departure

5-2. During which portion of an air trajectory will the air resistance offer the greatest retardation to a projectile?

1. End
2. Middle
3. Beginning
4. Apex

5-3. During which portion of an air trajectory will the maximum ordinate occur?

1. Nearer the beginning
2. Nearer the end
3. At the middle
4. At the point of maximum air resistance

5-4. To achieve the same range with an air shot as with a vacuum shot, which of the following changes, if any, must be made?

1. Increase angle of departure
2. Decrease angle of departure
3. Decrease angle of fall
4. No change is necessary

5-5. During which portion of an air trajectory will the density of the air offer the least retardation to a projectile?

1. Beginning
2. Lower portion
3. Upper portion
4. End

5-6. Assuming that the alternatives listed all have an initial velocity of 2600 ft/sec, which trajectory will be affected the most by air resistance?

1. 5" projectile
2. 8" projectile
3. 3" projectile
4. 16" projectile

5-7. The effect of the projectile shape on the air resistance is quantitatively expressed by the

1. projectile diameter
2. projectile circumference
3. coefficient of form
4. coefficient of rounding

5-8. Why are modern naval guns rifled?

1. To counteract the effect of drift
2. To solve for wind effect on range and deflection computations
3. To keep the projectile pointing along its trajectory
4. To increase the striking velocity

5-9. What harmful effect to a projectile's trajectory is caused by the rifling in a gun barrel?

1. Drift
2. Rigidity
3. Resistance
4. Precession

5-10. Which of the following ballistic factors causes the effects of wind upon a projectile to increase?

1. Elevation
2. Initial velocity
3. Range
4. Angle of departure

5-11. Which of the following projectiles would be LEAST affected by wind if all had the same initial velocity?

1. 5"
2. 8"
3. 3"
4. 16"

5-12. Wind that blows with or against the flight path of a projectile is called

1. head wind
2. tail wind
3. range wind
4. cross wind

5-13. In order to make proper gun settings to compensate for the effects of wind, true wind must be resolved into which of the following components?

1. In line and perpendicular
2. In line and vertical
3. Horizontal and vertical
4. Vertical and perpendicular

5-14. Which of the following types of wind is used to compensate a trajectory that passes through winds moving in opposite directions?

1. True wind
2. Range wind
3. Cross wind
4. Weighted ballistic wind

5-15. The earth's rotation noticeably affects projectiles with a range exceeding how many yards?

1. 10,000
2. 15,000
3. 20,000
4. 25,000

5-16. Which of the following guns require a correction for the effects of Coriolis force?

1. 40 m/m
2. 3" 50
3. 5" 38
4. 16"

Learning Objective: Describe the construction and use of range tables, and demonstrate the use of the Air Density Nomogram.

5-17. What type of publication are range tables?

1. Rate Training Manual
2. NAVORD Ordnance Data (ODs)
3. NAVORD Ordnance Pamphlet (OPs)
4. NAVSEA manual

USE THE RANGE TABLE IN FIGURE 5-12 OF THE TEXTBOOK FOR QUESTIONS 5-18 THROUGH 5-20.

5-18. What angle of departure in degrees and minutes is required to fire a 5" 54 gun 7,100 yards?

1. 2° 55.4'
2. 2° 56.8'
3. 4° 9.4'
4. 4° 19.3'

5-19. What angle of departure in minutes is required to obtain a range of 6,500 yards with a 5" 54 gun?

1. 230.2 minutes
2. 234.9 minutes
3. 239.7 minutes
4. 244.5 minutes

5-20. At a range of 6,800 yards, how much drift will there be and what direction will this drift take?

1. 4.9 yards, right
2. 4.9 yards, left
3. 5.5 yards, right
4. 5.5 yards, left

5-21. Standard atmospheric ballistic computations are based on a sea level temperature of ___(a)___ and a barometric pressure of ___(b)___ inches.

1. (a) 32°F (b) 29.43
2. (a) 59°F (b) 29.53
3. (a) 72°F (b) 29.63
4. (a) 75°F (b) 29.73

5-22. When the air density is 10 percent below standard, what angle of departure is required to hit a target at a range of 7,000 yards?

1. 4° 4.5'
2. 4° 9.4'
3. 4° 14.3'
4. 4° 19.3'

5-23. When the air density is 5 percent below standard, what angle of departure is required to hit a target at a range of 6,200 yards?

1. 3° 27.2'
2. 3° 31.7'
3. 3° 36.2'
4. 3° 40.8'

IN ANSWERING QUESTIONS 5-24 AND 5-25, REFER TO THE AIR DENSITY NOMOGRAM, FIGURE 5-13 OF THE TEXT.

5-24. When the surface air density is 102% and the range is 10,000 yards, how much change in range is required to hit a target?

1. -80 yds
2. +80 yds
3. -60 yds
4. +60 yds

5-25. Assume that the barometric pressure is 29 inches and the temperature is 64° Fahrenheit. What will be the change in range for a low-level elevation range of 6000 yds?

1. -40 yds
2. +40 yds
3. +50 yds
4. -50 yds

5-26. Which of the following factors is a reason guns in the fleet seldom produce the designed initial velocity?

1. Air density
2. Coriolis force
3. Variations in powder weight
4. Barrel erosion

5-27. The number of equivalent service rounds fired is calculated in what way?

1. By adding the service rounds and equivalent target rounds
2. By totaling the service rounds
3. By subtracting the equivalent target rounds from the service rounds
4. By totaling the target rounds

5-28. Which of the following ballistic factors are measured with a star gage?

1. Gun barrel erosion
2. Powder charge temperature
3. Projectile weight
4. Initial velocity

5-29. Powder at a temperature of 75°F will change the U of a 5" gun by which of the following amounts?

1. 30 ft/s less
2. 30 ft/s more
3. 15 ft/s less
4. 15 ft/s more

5-30. Assume that barrel enlargement of a gun produces a U loss of 20 ft/sec and that the temperature of the powder used is 75° Fahrenheit. What is the angle of departure required to hit a target at a range of 7,100 yards?

1. 4° 14.3'
2. 4° 19.3'
3. 4° 24.3'
4. 4° 29.4'

5-31. The range table shown in Figure 5-12 of the textbook was developed for projectiles with a standard weight of how many pounds?

1. 25 lb
2. 45 lb
3. 65 lb
4. 70 lb

5-32. The expression "GUN BALLISTIC IN RANGE" refers to which of the following factors?

1. Total correction to range due to initial velocity
2. Total correction to range due to ballistic conditions
3. Total effect of initial velocity on range
4. Total effect of ballistic conditions on range

5-33. After a gunfire support exercise is completed, what information is used as criterion to judge the accuracy of the projectiles' impact point?

1. Fire control system's computation
2. Shore spotter's observation data
3. Range table data
4. Weapon officer's observation data

Learning Objective: Identify the factors required in the computation of initial velocity.

IN ANSWERING QUESTIONS 5-34 THROUGH 5-39, REFER TO THE INITIAL VELOCITY COMPUTATION (iv) FORM SHOWN IN FIGURE 5-15 OF THE TEXT.

5-34. The powder temperature used in the iv computation should be the average magazine temperature of what minimum number of days preceding actual use?

1. 1
2. 2
3. 3
4. 4

5-35. How often are erosion gage readings taken for use in the iv computation?

1. Every 3 months
2. After every 50 rounds fired
3. After either 1 or 2 above, whichever occurs first
4. After each firing exercise

5-36. The air density correction from the range tables used in the iv computation is based on which of the following combinations of factors?

1. Projectile/fuze
2. Projectile weight/powder temperature
3. Powder temperature/star gage reading
4. Projectile/range

5-37. Which of the following quantities is used to correct for unaccountable errors during surface gunfire?

1. P.E.S.R.
2. ACTH
3. P.I.
4. P.T.

5-38. Which of the following ballistic quantities is calculated on the B portion of the iv form?

1. Range error
2. Air density compensation
3. Angle of departure
4. ACTH

5-39. Which of the following entries on the B portion of the iv computation form contains the correction for Earth curvature?

1. B-8
2. B-7
3. B-6
4. B-5

5-40. The velocity loss versus erosion gage table is located in which of the following publications?

1. OP 1182
2. OD 1182
3. OP 2332
4. OD 2435

QUESTION 5-41 IS TO BE JUDGED TRUE OR FALSE.

5-41. A powder charge that is below standard temperature will cause a gain in the initial velocity of the projectile.

1. True
2. False

5-42. The initial velocity setting entered in the computer is obtained by algebraically adding which of the following quantities to the nominal velocity?

1. The velocity loss entry from item C-2 of the iv computation form
2. The total velocity correction from item C-5 of the iv computation form
3. The sum of the iv form loss column
4. The sum of the iv form gain column

Learning Objective: Identify the frames of reference; basic lines, angles, and planes; coordinate systems; and units of measure used in the gun fire control problem.

5-43. Target position is measured and lead angles are computed within a system of lines, angles, and planes called a

1. frame of reference
2. system of vectors
3. geometric system
4. rectangular frame

5-44. The size and direction of a quantity can be represented as a

1. plane
2. trajectory
3. vector
4. frame of reference

5-45. Which of the following conditions describe the frames of reference that are attached (a) to ownship and (b) to the earth?

1. (a) Unstable (b) unstable
2. (a) Stable (b) stable
3. (a) Unstable (b) stable
4. (a) Stable (b) unstable

5-46. With respect to what planes are measurements made for Earth frame of reference?

1. Horizontal and normal
2. Horizontal and vertical
3. Deck and vertical
4. Deck and normal

5-47. Measurements for ownship frame of reference are made with respect to which of the following planes?

1. Horizontal and normal
2. Horizontal and vertical
3. Deck and vertical
4. Deck and normal

5-48. What are the two basic lines used to solve the ballistic portion of the fire control problem?

1. N-S and E-W axis lines
2. Line of sight (los) and line of fire (lof)
3. Line of fire (lof) and ownship center line (OS CL)
4. Ownship center line (OS CL) and line of sight (los)

5-49. The term horizontal is used in naval ordnance for an imaginary plane that is tangent to the

1. ship's deck at your gun's position
2. earth's surface at your gun's position
3. gun bore axis at the ship's deck
4. surface of the ocean at the ship's position

5-50. What basic angle or line is used as the primary reference in establishing the position of the gun?

1. Angle of elevation
2. Sight angle
3. Line of fire
4. Line of sight

5-51. When positioning a gun to hit a target, what total number of lead angles are used?

1. One
2. Two
3. Three
4. Four

5-52. Sight angle as shown in figure 5-18 of the textbook is measured in which of the following reference frames?

1. The horizontal plane that contains the trunnion axis and the los
2. The horizontal plane that contains the trunnion axis and the lof
3. A plane perpendicular to the trunnion axis and containing the los
4. A plane perpendicular to the trunnion axis and containing the lof

5-53. Sight deflection as shown in figure 5-18 of the textbook is measured in which of the following reference frames?

1. The horizontal plane which contains the trunnion axis and the los
2. The horizontal plane which contains the trunnion axis and the lof
3. A plane perpendicular to the trunnion axis and containing the los
4. A plane perpendicular to the trunnion axis and containing the lof

5-54. What total number of basic coordinate systems are used to locate a point in a plane?

1. One
2. Two
3. Three
4. Four

5-55. What types of coordinates are used in a rectangular coordinate system to determine the position of a surface target?

1. One linear and one angular
2. Two linear only
3. Two linear and one angular
4. Three linear

5-56. Position of a surface target is determined in a polar coordinate system by the use of

1. one linear and one angular coordinate
2. two linear and one angular coordinates
3. two linear coordinates only
4. three linear coordinates

5-57. What type of three-dimensional coordinate system is used when an angular value is used to describe a point's deviation from the reference plane?

1. Linear
2. Polar
3. Rectangular
4. Spherical

5-58. What type of three-dimensional coordinate system employs linear coordinates to describe a point's deviation from the reference plane?

1. Linear
2. Polar
3. Rectangular
4. Spherical

5-59. In what units of measure are ownship speed, target speed, and wind velocity (a) received in a computer and (b) used within a computer?

1. (a) Knots (b) yards/hour
2. (a) Yards/hour (b) knots
3. (a) Knots (b) yards/second
4. (a) Yards/hour (b) yards/second

5-60. What is the constant ratio used to convert knots to yards per second?

1. 0.365
2. 0.635
3. 0.536
4. 0.563

5-61. Which of the following units of measure is a convenient unit to use when converting between angular and linear measure?

1. Knots
2. Yards per second
3. Radians
4. Degrees per second

5-62. The MIL is equal to how many minutes of arc?

1. 1000.0
2. 58.18
3. 3.438
4. 5.718

5-63. The linear value of the MIL will vary due to changes in which of the following target parameters?

1. Range
2. Bearing
3. Elevation
4. Speed

5-64. What is the linear value of a MIL at a range of 5000 yards?

1. 0.5 yards
2. 5.0 yards
3. 50.0 yards
4. 500.0 yards

5-65. Assume that a target being tracked at a range of 5,000 yards has a linear bearing rate of 50 knots. What will be the angular bearing rate?

1. 56.30 mils per second
2. 5.63 mils per second
3. 56.30 yards per second
4. 5.63 yards per second

5-66. Assume that a target being tracked at a range of 10,000 yards has a linear bearing rate of 150 knots. What will be the angular bearing rate expressed in minutes of arc per second?

1. 5.63
2. 29.04
3. 56.30
4. 290.40

5-67. What units of measurement normally express the rates used to predict the target's future position?

1. Knots for all three coordinates
2. Knots, yards per second, and mils
3. Yards per second for all three coordinates
4. Mils for two coordinates and yards per second for one coordinate

5-68. What units of measurement are normally used for the rates involved in the coordinate system of the target-tracking section of the GFCS?

1. Knots for all three coordinates
2. Knots, yards per second, and mils
3. Yards per second for all three coordinates
4. Mils for two coordinates and yards per second for one coordinate

Assignment 6

The Gun Fire Control Problem (continued) and Fundamentals of Analog Computers

Textbook Assignment: FTG 3 & 2, NAVEDTRA 10207-B; pages 5-29 through 6-14

Learning Objective: Identify and interpret standard fire control symbols.

6-1. Which of the following publications provides a detailed coverage of the construction and definition of fire control symbols?

1. NAVEDTRA 10052 (Series)
2. OP 1700, Vols. 1, 2, and 3
3. NAVPERS 18068-C
4. Each of the above

6-2. What volume of the Standard Fire Control Symbols publication contains information that is primarily applicable to the gun fire control problem?

1. Vol. 1
2. Vol. 2
3. Vol. 3
4. Vol. 4

6-3. The basic fire control symbol represents which of the following information in each class?

1. The system type
2. The geometric quantity
3. The method used in problem solution
4. The algebraic sum

QUESTION 6-4 IS TO BE JUDGED TRUE OR FALSE.

6-4. The quantity modifier in a fire control symbol may be placed either before or after the parenthesis without affecting the meaning of the symbol.

1. True
2. False

TO ANSWER QUESTIONS 6-5 THROUGH 6-7, SELECT FROM COLUMN B THE SYMBOL CONSTRUCTION WHICH CORRESPONDS TO THE GEOMETRICAL QUANTITY IN COLUMN A.

	A. QUANTITIES	B. SYMBOLS
6-5.	Apparent wind speed	1. W
6-6.	Horizontal true wind speed	2. Wa
		3. Wh
6-7.	True wind speed	4. Wo

TO ANSWER QUESTIONS 6-8 THROUGH 6-10, SELECT FROM COLUMN B THE SYMBOL CONSTRUCTION WHICH CORRESPONDS TO THE GEOMETRICAL QUANTITY IN COLUMN A.

	A. QUANTITIES	B. SYMBOLS
6-8.	Horizontal deflection	1. Ed
6-9.	Director train	2. Lh
6-10.	Target height	3. Ls
		4. Rv

6-11. In the construction of fire control symbols, which of the following statement applies to the use of quantity modifiers?

1. The geometrical quantity is enclosed in parenthesis
2. The quantity modifier may preceed the geometrical quantity
3. The quantity modifier may follow the geometrical quantity
4. Each of the above

TO ANSWER QUESTIONS 6-12 THROUGH 6-14, SELECT FROM COLUMN B THE SYMBOL CONSTRUCTION WHICH CORRESPONDS TO THE GEOMETRICAL QUANTITY IN COLUMN A.

	A. QUANTITIES	B. SYMBOLS
6-12.	Deflection spot	1. c(R)
6-13.	Generated range	2. q(Ls)
6-14.	Increments of generated elevation	3. pl(Edg')
		4. ic(E)

Learning Objective: Solve the elements of the surface fire control problem affected by ownship and target motion.

6-15. When measured by the director, the present target position is referenced to which of the following planes?

1. The deck plane
2. The horizontal plane
3. The vertical plane
4. The normal plane

6-16. Which of the following planes is used to make deck tilt corrections needed for computation of the fire control problem?

1. The deck plane
2. The horizontal plane
3. The vertical plane
4. The normal plane

6-17. What quantity is obtained when director elevation and level angle are combined?

1. Present target position
2. Target rate of climb
3. Target bearing angle
4. Target elevation angle

6-18. How is slant range affected, if at all, by an inbound air target?

1. It increases
2. It decreases
3. It is not affected
4. It cannot be determined

6-19. The angle between the los and the lof is called the

1. sight angle
2. level angle
3. crosslevel angle
4. traverse angle

6-20. Which of the following quantities is added to director train to obtain gun train?

1. Sight deflection
2. Sight angle
3. Level angle
4. Trunnion tilt

Learning Objective: Identify and define the geometric problems contained in the gun fire control problem.

6-21. What total number of basic steps are involved in the solution of the gun fire control problem?

1. Five
2. Two
3. Three
4. Four

6-22. What is used as the basic reference in the solution of the gun fire control geometry problems?

1. The deck plane
2. The reference director
3. The horizontal plane
4. The reference gun mount

6-23. During which of the following computations is target position converted from deck to horizontal plane reference?

1. Future position
2. Ballistic
3. Parallax
4. Present position

6-24. What quantities are computed from the errors obtained by comparing target position with generated target position?

1. Angular rates
2. Linear rates
3. Stabilization corrections
4. Initial velocity corrections

6-25. Which of the following quantities is dependent on both Ei and Zd?

1. B
2. Bd
3. j(Bd)
4. By

6-26. What quantity is produced by adding ship's course (Co) to relative bearing (B)?

1. Bd
2. By
3. j(Bd)
4. p(Bd)

6-27. In and across what reference line are present position linear rates computed?

1. The los
2. The lof
3. The OSCL
4. The TCL

IN ANSWERING QUESTIONS 6-28 THROUGH 6-30, REFER TO FIGURE 5-32 OF THE TEXT.

6-28. Which vector represents ownship motion?

1. DMht
2. DMho
3. DMrho
4. DMrht

6-29. How is target speed represented?

1. By the direction of vector DMho
2. By the magnitude of vector DMho
3. By the direction of vector DMht
4. By the magnitude of vector DMht

6-30. Which of the following quantities is found by algebraically adding the components in the figure that are perpendicular to the line of sight?

1. DMrh
2. DMb
3. Bot
4. By

6-31. Which of the following quantities represents the target's rate of vertical linear movement in elevation?

1. Rh
2. Rv
3. DMv
4. DMr

Learning Objective: Solve the element of the surface fire control problem that determines future target position.

6-32. The first step in determining a target's future position is the multiplication of the relative motion rates DMv, DMrh, and DMb by which of the following quantities?

1. T_1
2. T_2
3. Rh
4. Rv

IN ANSWERING QUESTION 6-33, REFER TO FIGURE 5-37 OF THE TEXT.

6-33. What quantity is produced when Sh and Wbg(Lh) are combined?

1. Rh_2
2. Mb
3. Mbg
4. Lh

IN ANSWERING QUESTION 6-34, REFER TO FIGURE 5-38 OF THE TEXT.

6-34. What quantity is produced when angles E4 and V4 are combined?

1. Eg
2. Sh
3. Lh
4. Wbq(Lh)

6-35. In which section of a fire-control computer are the gun orders compiled?

1. Present position
2. Future position
3. Trunnion tilt
4. Ballistic

6-36. Which of the following displacements is/are compensated for by parallax corrections?

1. Horizontal displacement of gun from director only
2. Vertical displacement of gun from director only
3. Horizontal and vertical displacements of gun from director
4. Displacement of director above the waterline

6-37. In what plane is horizontal base length measured?

1. Deck
2. Slant
3. Roller path
4. Horizontal

6-38. What base length is used for pl(Edg')h?

1. 5 yd
2. 10 yd
3. 50 yd
4. 100 yd

6-39. Horizontal parallax is affected by which of the following measurements?

1. Range
2. Bearing
3. Base length
4. All of the above

6-40. What base length is used for pl(Bdg')?

1. 5 yd
2. 10 yd
3. 50 yd
4. 100 yd

6-41. The output of the horizontal parallax computer must be adjusted by means of a gear ratio at receiving unit when which of the following situations exists?

1. Two directors are used
2. Base length is different from 100 yd
3. Bd instead of Bdg' is used for computing b'
4. Ei' and Z are measured by a director rather than by the stable vertical

Learning Objective: Define and analyze scale factors related to analog computers.

6-42. An analog computer converts and correlates the factors of one system into a more convenient system by which of the following means?

1. Application
2. Pulsation
3. Simulation
4. Solution

6-43. An analog computer that is used in a fire control system solves the fire control problem by using which of the following computing components?

1. Mechanical computing components
2. Electrical computing components
3. Electromechanical computing components
4. Each of the above

6-44. What is the scale factor of a synchro where one revolution of its shaft represents a distance of 72 yards?

1. 0.01389 rev/yd
2. 0.01389 yd/rev
3. 72 rev/yd
4. 72 degrees/rev

6-45. Which of the following degrees of arc will represent 100 yards with the largest scale factor?

1. 10°
2. 30°
3. 60°
4. 90°

6-46. What is the analog units value for a maximum range of 30,000 yards in a computer that has a scale factor of 1 volt to 150 yards?

1. 100 V
2. 200 V
3. 300 V
4. 400 V

6-47. What feature of a computer limits the size of the scale factor used?

1. Accuracy
2. Dependability
3. Size
4. Speed

Learning Objective: Identify the types and basic operating principles of mechanical computing elements designed for solving linear functions.

6-48. What total number of basic types of mechanical summation devices are used in analog computers?

1. One
2. Two
3. Three
4. Four

6-49. Which of the following differential summation devices is most commonly used?

1. A bevel gear
2. A spur gear
3. A planetary gear
4. A worm gear

IN ANSWERING QUESTION 6-50, REFER TO FIGURE 6-3 OF THE TEXT.

6-50. What will be the output of the bevel gear differential if the end gears are rotated at the same speed but in opposite directions?

1. Zero output
2. Output twice the speed of the input
3. Output one half the speed of the input
4. Output equal to the input speed

6-51. What must be done to the output of a bevel gear differential to obtain a correct representation of the sum or difference?

1. Divide by 2
2. Multiply by 2
3. Add a constant of 2
4. Subtract a constant of 2

6-52. What total number of ways of obtaining an output is possible when using a bevel gear differential?

1. One
2. Two
3. Three
4. Four

6-53. What total number of types of mechanical multipliers is commonly used?

1. One
2. Two
3. Three
4. Four

6-54. In what form are the inputs to the rotary screw type multiplier?

1. Scaled voltages
2. Unscaled voltages
3. Shaft values
4. Potentiometer values

QUESTION 6-55 IS TO BE JUDGED TRUE OR FALSE.

6-55. If either input rack of a screw-type multiplier is moved from its zero position, an output will be produced.

1. True
2. False

6-56. What type of mechanical multiplier is used when one of the inputs is a constant?

1. A rack
2. A sector
3. A cam
4. A linkage

6-57. How are division problems most generally solved in a computer?

1. By electrical devices
2. By mechanical devices
3. By hydraulic devices
4. By rearrangement of the problem

Learning Objective: Identify the types and basic operating principles of mechanical computing elements designed to solve nonlinear functions.

6-58. Which of the following mechanical devices convert mechanical motion from angular to linear?

1. Multiplier
2. Linkage
3. Differential
4. Cam

6-59. What type of cam may be used to represent an exponential function?

1. A squaring cam
2. A tangent cam
3. A reciprocal cam
4. A ballistic cam

6-60. The tangent cam produces trigonometric functions for which of the following sets of angles?

1. Below 90°
2. Between 90° and 180°
3. Above 180°
4. Between 180° and 270° only

6-61. What type of cam is used when converting a division problem to a multiplication problem?

1. A squaring cam
2. A tangent cam
3. A reciprocal cam
4. A ballistic cam

6-62. What type of function does the ballistic cam represent?

1. Reciprocal
2. Empirical
3. Exponential
4. Trigonometric

6-63. Which of the following computing devices separates a vector into its two rectangular components?

1. A linkage angle resolver
2. A multiplying linkage
3. A sector type multiplier
4. A component solver

6-64. Which of the following computing devices solves for the sine and cosine function of an angle?

1. A linkage angle resolver
2. A multiplying linkage
3. A sector type multiplier
4. A component solver

6-65. Which of the following processes is a continuous summation of changes in a variable with respect to time?

1. Integration
2. Angle resolution
3. Component resolution
4. Empirical resolution

6-66. What is the prime mover for the disk in a mechanical integrator?

1. Range rate
2. Time motor
3. Elevation input
4. Train input

6-67. Into what part of a ball-disk-roller integrator is the range rate fed?

1. Disk input gear
2. Carriage input gear
3. Disk
4. Roller

Assignment 7

Fundamentals of Analog Computers (Continued)

Textbook Assignment: FTG 3 & 2, NAVEDTRA 10207-B; pages 6-15 through 6-43

Learning Objective: Identify the types and operating principles of the electromechanical computing elements used in analog computers.

7-1. What is the electrical computing variable for most modern analog computers?

1. Current
2. Resistance
3. Voltage
4. Watts

7-2. For which of the following functions are potentiometers (pots) used in electromechanical analog computers?

1. To convert shaft position to an electrical voltage
2. To multiply and divide
3. To generate nonlinear functions
4. Each of the above

7-3. In the construction of precision pots, a wire-wound resistance element is used because, compared to carbon, wire has which of the following characteristics?

1. A lower reactance to high frequency currents
2. A noise level
3. A resistance per unit length
4. A distortion level

7-4. A total of how many basic types of potentiometers is used in analog computers?

1. One
2. Two
3. Three
4. Four

7-5. A variable resistor whose output voltage does NOT vary at a constant rate as the slider is moved across the resistance element is called a

1. nonlinear pot
2. linear pot
3. rheostat
4. varistor

7-6. A potentiometer that is used to tap off 20 volts of a constant 80-volt supply has had its shaft rotated what percent of full rotation from zero to maximum?

1. 20
2. 25
3. 75
4. 80

IN ANSWERING QUESTIONS 7-7 THROUGH 7-9, REFER TO FIGURE 6-21 OF THE TEXT.

7-7. What is the mechanical scale factor for the pot?

1. 0.0001 rev/yd
2. 0.0005 V/yd
3. 30 V/rev
4. 90,000 yd/rev

7-8. Which of the following is the electrical scale factor for the pot?

1. 0.005 V/yd
2. 0.020 rev/V
3. 3,000 yd/V
4. 5,000 yd/V

7-9. Assume E_o is 15 volts. What should the range dial read?

1. 15,045
2. 20,018
3. 35,000
4. 45,045

FOR QUESTIONS 7-10 THROUGH 7-14, THE KNOWN DATA IS 62.5 V/rev, 50 Ein, and .0005 V/yd.

IN ANSWERING QUESTIONS 7-10 AND 7-11, REFER TO FIGURE 6-22 AND TABLE 6-1 OF THE TEXT.

7-10. What is the mechanical scale factor for the pot?

1. 50,000 yd/rev
2. 100,000 yd/rev
3. 125,000 yd/rev
4. 150,000 yd/rev

7-11. What is the maximum degree of rotation of the pot?

1. 220°
2. 288°
3. 320°
4. 388°

IN ANSWERING QUESTIONS 7-12 THROUGH 7-14, REFER TO FIGURE 6-23 AND TABLE 6-1 OF THE TEXT.

7-12. What is the electrical scale factor for the pot?

1. 1,600 yd/V
2. 2,000 yd/V
3. 2,500 yd/V
4. 5,000 yd/V

7-13. With a full travel of 360 degrees for the slider on the pot, what is the (a) output voltage E_o and the (b) range in yards that represents the output voltage for a mechanical input of 180 degrees?

1. (a) 25.00 V (b) 50,000 yd
2. (a) 25.00 V (b) 62,500 yd
3. (a) 31.25 V (b) 50,000 yd
4. (a) 31.25 V (b) 62,500 yd

7-14. With a full travel of 288 degrees for the slider on the pot, what is (a) the output voltage, E_o, and the (b) range in yards that the output voltage represents for a mechanical input of 180 degrees?

1. (a) 25 V (b) 50,000 yd
2. (a) 25 V (b) 62,500 yd
3. (a) 31.25 V (b) 50,000 yd
4. (a) 31.25 V (b) 62,500 yd

IN ANSWERING QUESTIONS 7-15 THROUGH 7-17, REFER TO FIGURE 6-24 OF THE TEXT.

7-15. With the slider of the pot positioned one-fifth of a revolution between terminal 4 (center) and terminal 2, what is the value of the output voltage E_o?

1. -8 volts
2. -6.4 volts
3. 6.4 volts
4. 8 volts

7-16. What is the electrical scale factor for the pot?

1. 0.025 rev/kn
2. 0.04 V/kn
3. 20 kn/V
4. 25 kn/kn/V

7-17. With the slider of the pot positioned to represent a range rate of 300 knots, what is the value of the output voltage E_o?

1. -12 volts
2. - 8 volts
3. 8 volts
4. 12 volts

7-18. To increase the accuracy of a pot output per degree of error of its slider, it is necessary to increase which of the following variables?

1. The total travel of the slider
2. The voltage per revolution of the slider
3. The mechanical scale factor of the pot
4. The electrical scale factor of the pot

7-19. At what angular separation are the sliders in a sine/cosine potentiometer?

1. 30°
2. 45°
3. 90°
4. 120°

7-20. The output voltage of a tachometer generator is proportional to which of the following properties of the input signal?

1. Amplitude
2. Velocity
3. Phase
4. Frequency

7-21. What source supplies the magnetic field for a d.c. tach?

1. An electromagnet
2. A permanent magnet
3. An a.c. supplied reference coil
4. A d.c. supplied reference coil

7-22. What characteristic of the output voltage from an a.c. tach is controlled by the direction of rotation of its rotor?

1. Polarity
2. Phase
3. Frequency
4. Amplitude

Learning Objective: Identify the electrical and electronic computing elements used in fire control analog computers.

7-23. What is the purpose of the capacitors connected across each resistor in a parallel resistor network?

1. To compensate for any unwanted inductance between windings of the resistor
2. To shunt any stray a.c. voltages
3. To integrate the output voltage
4. To differentiate the output voltage

7-24. What is the purpose of running the output of a network box through a coaxial cable?

1. To compensate for any unwanted inductance between resistors
2. To shunt any stray a.c. voltages
3. To protect personnel from hazardous voltages
4. To shield the output from stray pickup

7-25. The output voltage of a network box with resistors of equal resistance is equal to the

1. sum of the input voltages
2. product of the input voltages
3. sum of the input voltages divided by the number of resistors in the network
4. product of the input voltages less the number of resistors in the network

7-26. What components in the summing network circuit permit summation of voltages without scale changes?

1. Feedback resistors
2. Precision wire-wound resistors
3. Feedback amplifiers
4. Capacitors

7-27. What is the reason for using negative feedback in computing amplifiers?

1. To increase stage gain
2. To add to the input voltages
3. To control circuit amplification
4. To reduce output voltages

IN ANSWERING QUESTIONS 7-28 AND 7-29, REFER TO FIGURE 6-30 OF THE TEXT.

7-28. Which resistor provides the required resistive load for the feedback amplifier?

1. R_1
2. R_2
3. R_f
4. R_L

7-29. The overall loop amplification is determined by the resistance ratio of which of the following circuit components?

1. R_1 to R_2
2. R_f to R_L
3. R_f to R_1 and R_2
4. R_L to R_1 and R_2

7-30. What is the real job of a summing loop in an analog computer?

1. To sum analog voltages
2. To determine the algebraic sum of computer variables
3. To produce the algebraic sum of two voltages of any phase
4. To sum errors resulting from out of phase voltages

IN ANSWERING QUESTION 7-31, REFER TO FIGURE 6-31 OF THE TEXT.

7-31. With a value of 6 volts for E_s, what is the value of E_f?

1. - 3 V
2. - 6 V
3. -12 V
4. -18 V

7-32. What is the maximum effective resistance between the output terminals of an amplifier that has negative feedback?

1. Less than 1 ohm
2. 100 ohms
3. .01 megohm
4. 1 megohm

IN ANSWERING QUESTIONS 7-33 THROUGH 7-35, REFER TO FIGURE 6-32 OF THE TEXT.

7-33. With E_s equal to 6 volts, what is the value of E_f?

1. - 3 V
2. - 6 V
3. -12 V
4. -18 V

7-34. If the input scale factor were 150 Kn/V with an input of 6 volts, what would the output scale factor be, expressed as Kn/V?

1. 100 Kn/V
2. 200 Kn/V
3. 300 Kn/V
4. 400 Kn/V

7-35. With an input of 6 volts, a total of how much current flows through resistor R_s?

1. 0.0000015A
2. 0.0000025A
3. 0.0000030A
4. 0.0000035A

7-36. Whenever possible, which of the following values of R_f should be used in the network box of a summing computing loop?

1. R_f = .1 megohm
2. R_f = 1 megohm
3. R_f = 5 megohms
4. R_f = 10 megohms

7-37. What constant is included in the circuit design of a computing network that converts knots to yards per second?

1. 0.563
2. 1:2 R_f/R_s ratio
3. 1.776
4. 0.000001A

IN ANSWERING QUESTION 7-38, REFER TO FIGURE 6-33 AND TABLE 6-3 OF THE TEXT.

7-38. With E_s equal to 0.5 volt, what is the (a) output voltage and the (b) output in yards per second represented by this voltage?

1. (a) -0.282 V (b) 14.08 yds/s
2. (a) -0.300 V (b) 15.00 yds/s
3. (a) -0.450 V (b) 22.52 yds/s
4. (a) -0.500 V (b) 25.00 yds/s

IN ANSWERING QUESTIONS 7-39 AND 7-40. REFER TO FIGURE 6-34 OF THE TEXT.

7-39. What constant is included in the design of the illustrated circuit?

1. 0.563
2. 2.000
3. 3
4. 1.5

7-40. With an input voltage of 0.5 volt, (a) what is the output voltage, and (b) what is the distance in feet represented by this voltage?

1. (a) -0.3 V (b) 81 ft
2. (a) -0.5 V (b) 135 ft
3. (a) -1.5 V (b) 405 ft
4. (a) -3.0 V (b) 810 ft

7-41. A gain compensating resistor must be included in the design of a computing loop to compensate for which of the following loss factors?

1. Input impedance
2. Stray capacitance
3. Feedback resistance
4. Output impedance

7-42. How is the compensating resistor connected in a computing loop?

1. Parallel with the feedback resistor
2. Series with the feedback resistor
3. Series with the input resistor
4. Parallel with the load resistor

7-43. What is the formula for computing the size of the gain compensating resistor for a feedback amplifier?

1. $R_g = \frac{E_s - E_f}{I_s - I_a}$
2. $R_g = \frac{E_s - E_a}{I_s - I_f}$
3. $R_g = \frac{E_f - E_a}{I_f - I_a}$
4. $R_g = \frac{E_f - E_s}{I_a - I_s}$

Learning Objective: Evaluate summation loop computations in analog computers.

QUESTION 7-44 IS TO BE JUDGED TRUE OR FALSE.

7-44. The output of analog summation loops may be either electrical or mechanical.

1. True
2. False

IN ANSWERING QUESTIONS 7-45 THROUGH 7-47, REFER TO FIGURE 6-37 OF THE TEXT.

7-45. Use an input voltage of 6 volts each for E_1, E_2, and E_3. (a) What is the output voltage, and (b) how many yards are represented by this voltage?

1. (a) - 2.8 V (b) 4200 yd
2. (a) - 4.2 V (b) 5200 yd
3. (a) - 9.2 V (b) 13800 yd
4. (a) -18.0 V (b) 18000 yd

7-46. What is the resistance ratio of R_f to each input resistor?

1. 1:1
2. 1:2
3. 1:3
4. 3:1

QUESTION 7-47 IS TO BE JUDGED TRUE OR FALSE.

7-47. The feedback to input resistance ratio is designed to cause a change in the scale factor of the output.

1. True
2. False

7-48. When the network box is designed for a summing computing loop, which factor in an amplifier must not be exceeded?

1. The cutoff frequency
2. The distortion level
3. The noise level
4. The saturation point

IN ANSWERING QUESTION 7-49, REFER TO FIGURE 6-38 OF THE TEXT.

7-49. Use an input voltage of 6 volts each for E1 and E2 and minus 6 volts for E3. (a) What is the output voltage, and (b) how many knots are represented by this voltage?

1. (a) - 2.8 V (b) 420 Kn
2. (a) - 4.2 V (b) 420 Kn
3. (a) - 9.2 V (b) 1380 Kn
4. (a) -18.0 V (b) 1800 Kn

IN ANSWERING QUESTION 7-50, REFER TO FIGURE 6-39 OF THE TEXT.

7-50. Why is the summation loop NOT suitable for use in a computer that uses 12 V as a reference voltage?

1. The amplifier would saturate
2. The maximum scale factor would be exceeded
3. It does not produce a common scale factor
4. The amplifier would not saturate

IN ANSWERING QUESTION 7-51, REFER TO FIGURE 6-40 OF THE TEXT.

7-51. Use an input voltage of 6 volts each for E_1 and E_2 and minus 6 volts for E_3. (a) What is the output voltage, and (b) how many knots are represented by this voltage?

1. (a) - 2.8 V (b) 420 Kn
2. (a) - 4.2 V (b) 420 Kn
3. (a) - 9.2 V (b) 1380 Kn
4. (a) -18.0 V (b) 1800 Kn

7-52. What is the maximum value for input leg resistors in a computing loop?

1. 1 megohm
2. 2 megohms
3. 3 megohms
4. 4 megohms

IN ANSWERING QUESTIONS 7-53 THROUGH 7-56, REFER TO FIGURE 6-42 OF THE TEXT. SUBSTITUTE RESISTOR VALUES OF R_1 = 2.0 MEGOHMS, R_2 = 0.2 MEGOHM, AND R_s = 2.0 MEGOHMS.

7-53. Compute the value of R_t for the input circuit.

1. 1.090909 megohms
2. 1.181818 megohms
3. 2.090909 megohms
4. 2.181818 megohms

7-54. With E1 equal to 11 volts, what is the total current flow through R2?

1. 0.5 μA
2. 1 μA
3. 5 μA
4. 10 μA

7-55. A total of how much current flows through R_s?

1. 0.5 μA
2. 1 μA
3 5 μA
4. 10 μA

7-56. What is the effective resistance of the single divider network?

1. 6 megohms
2. 12 megohms
3. 24 megohms
4. 30 megohms

IN ANSWERING QUESTION 7-57, REFER TO FIGURE 6-45.

7-57. What type of circuit(s) is/are used to reduce the value of the two resistors R_2 and R_3 below 3 megohms?

1. Two single divider network circuits
2. Two reshaping circuits
3. A multiple divider network circuit
4. A connecting circuit

IN ANSWERING QUESTION 7-58, REFER TO FIGURE 6-46 OF THE TEXT.

7-58. Assume that R_2 equals 2 megohms, R_3 equals 1 megohm, and R_c equals 2 megohms. Find the effective resistance of the E_2 leg and the E_3 leg.

1. E_2 leg = 4 megohms, E_3 leg = 6 megohms
2. E_2 leg = 5 megohms, E_3 leg = 8 megohms
3. E_2 leg = 6 megohms, E_3 leg = 5 megohms
4. E_2 leg = 8 megohms, E_3 leg = 4 megohms

Learning Objective: Determine the methods and identify the devices used for voltage multiplying and dividing.

7-59. What method of multiplication is performed by a potentiometer?

1. Motion times motion
2. Volts times motion
3. Volts times volts
4. Position times motion

IN ANSWERING QUESTIONS 7-60 AND 7-61, REFER TO FIGURE 6-47 OF THE TEXT.

7-60. With an input of 5 volts to the circuit, and the slider of the potentiometer positioned to represent 30 seconds, (a) what is the value of the output voltage, and (b) what is the distance represented by this voltage?

1. (a) 1 V (b) 2,815 yd
2. (a) 2 V (b) 5,630 yd
3. (a) 3 V (b) 8,445 yd
4. (a) 4 V (b) 11,260 yd

7-61. With an input of 5 volts to the potentiometer and the slider positioned to represent 20 seconds, (a) what is the value of the output voltage, and (b) how many yards is represented by this voltage?

1. (a) 1 V (b) 2,815 yd
2. (a) 2 V (b) 5,630 yd
3. (a) 3 V (b) 8,445 yd
4. (a) 4 V (b) 11,260 yd

IN ANSWERING QUESTION 7-62, REFER TO FIGURE 6-48 OF THE TEXT.

7-62. How many (a) seconds and (b) yards per second are represented by inputs of 4 volts and +3 revolutions of the slider for the illustrated potentiometer?

1. (a) 20 sec (b) 337.8 yd/sec
2. (a) 25 sec (b) 563 yd/sec
3. (a) 25 sec (b) 675.6 yd/sec
4. (a) 30 sec (b) 844.5 yd/sec

7-63. A vacuum tube voltmeter should be used to measure the output voltage of a computing potentiometer for which of the following reasons?

1. The vtvm will not cause loading of the pot
2. The vtvm has a more accurate meter movement
3. The vtvm can measure lower voltages
4. The vtvm can measure higher voltages

7-64. What type of multiplication is used to obtain the electrical product of two mechanical variables?

1. Motion x motion
2. Volts x motion
3. Volts x volts
4. Motion x time

7-65. If two potentiometers are connected directly, why is the output inaccurate?

1. Because the first potentiometer loads the second
2. Because the second potentiometer loads the first
3. Because of the low impedance load
4. Because of the inductive interaction

IN ANSWERING QUESTION 7-66, REFER TO FIGURE 6-52 OF THE TEXT.

7-66. What method is commonly used to increase the power factor of the variable X?

1. Increasing the resistance of the ganged potentiometers
2. Decreasing the resistance of the ganged potentiometers
3. Adding additional ganged potentiometers
4. Adding additional isolation amplifiers

IN ANSWERING QUESTIONS 7-67 THORUGH 7-69, REFER TO FIGURE 6-53 OF THE TEXT.

7-67. The output of the ZN network box is equal to

1. X + y - Z
2. X - ZY
3. Y - XZ
4. Z - XY

7-68. The gain of the amplifier is controlled by which of the following inputs?

1. The applied input voltage
2. The X input
3. The Y input
4. Each of the above

7-69. Resistance R_1 in the divider loop is NOT used in the reciprocal loop illustrated in figure 6-54 of the text because X is always equal to

1. Z
2. the computer reference voltage
3. $\frac{1}{Y}$
4. the voltage across potentiometer R_1

IN ANSWERING QUESTIONS 7-70 THROUGH 7-72, REFER TO FIGURE 6-55 OF THE TEXT.

7-70. The output of the servomotor BG is proportional to

1. E_1
2. E_2
3. E_3
4. E_o

7-71. The constant K is equal to which of the following quantities?

1. $\frac{1}{E_3}$
2. $E_i \times E_3$
3. $E_o - E_2$
4. $E_i \div E_2$

7-72. How can a rate x time problem be solved using the servomultiplier shown?

1. By adding more potentiometers
2. By assigning scale factors
3. By assigning constants
4. By mathematical rearrangement

Assignment 8

Fundamentals of Analog Computers (Continued); Fundamentals of Digital Computers

Textbook Assignment: FTG 3 & 2, NAVEDTRA 10207-B; pages 6-43 through 7-24

Learning Objective: Determine the solution of trigonometric functions and coordinate rotation as performed by resolver loops in analog computers.

8-1. Why must the inputs to a resolver be fed through isolation amplifiers?

1. To filter out the d.c. component of the input signal
2. To filter out stray voltages
3. To amplify the input signal to the resolver
4. To match the low impedance of the resolver

8-2. The input voltages to a basic resolver loop have which of the following phase-shift relationships to the computer reference voltage?

1. 0° or 90° phase-shifted
2. 90° or 180° phase-shifted
3. 0° or 180° phase-shifted
4. 45° or 90° phase-shifted

8-3. In sign reversing and summation computing loops, the output of the amplifier is fed directly back to the network box as feedback voltage. The feedback in a resolver computing loop is obtained indirectly by applying the amplifier output to which of the following resolver windings?

1. The feedback winding
2. The stator winding only
3. The rotor winding only
4. The stator and rotor windings

8-4. In a resolver computing loop, how is unity gain achieved between the input and output?

1. A voltage step-up between stator and rotor windings
2. A voltage step-up between feedback and rotor windings
3. A voltage step-down between stator and rotor windings
4. A voltage step-down between feedback and rotor windings

8-5. How is the capacitance of the input and output coaxial cables of a resolver loop maintained uniform?

1. By the use of compensation networks
2. By cutting the cables to specific lengths
3. By the use of coils
4. By grounding the shields of the cables

IN ANSWERING QUESTION 8-6, REFER TO FIGURE 6-57 OF THE TEXT.

8-6. When the rotor is at electrical zero, a counterclockwise movement of the rotor will induce which of the following voltage phase relationships in the R2 winding?

1. A voltage in phase with Ea
2. A voltage out of phase with Ea
3. A voltage in phase with Eb
4. A voltage out of phase with Eb

8-7. The amount of voltage induced in the R1 rotor of a resolver that has been rotated 45° clockwise can be determined by which of the following formulas?

1. R1 = Ea Sin 45° + Eb Cos 45°
2. R1 = Ea Cos 45° + Eb Sin 45°
3. R1 = Ea Cos 45° - Eb Sin 45°
4. R1 = Ea Sin 45° - Eb Cos 45°

IN ANSWERING QUESTIONS 8-8 AND 8-9, REFER TO FIGURE 6-58 OF THE TEXT.

8-8. What leads would be measured to obtain the amount of feedback to the amplifier?

1. Rotor leads R1 and R2
2. Stator leads S1 and S2
3. Stator leads S3 and S4
4. Stator leads S5 and S6

8-9. Assume that R3 is used as the output rotor. Ea is positive, Eb is negative, and the rotor has been turned clockwise. By means of the table, determine which of the following formulas is the correct output function for the data given.

1. $+ Ea \cos\theta - Eb \sin\theta$
2. $- Ea \cos\theta + Eb \sin\theta$
3. $+ Ea \sin\theta + Eb \cos\theta$
4. $- Ea \cos\theta - Eb \sin\theta$

8-10. With the rotor of a resolver at its zero position, what is the (a) gain ratio and (b) the amount of phase shift in degrees between the input to its amplifier and the resolver output?

1. (a) 1:1 (b) 0°
2. (a) 1:2 (b) 0°
3. (a) 1:1 (b) 90°
4. (a) 1:2 (b) 90°

8-11. The (a) inputs and (b) output(s) of a resolver used for the resolution of a vector are of what type?

1. (a) One electrical and one mechanical
   (b) one mechanical
2. (a) Two electrical and one mechanical
   (b) one electrical
3. (a) One electrical and one mechanical
   (b) two electrical
4. (a) Two electrical and one mechanical
   (b) two electrical

IN ANSWERING QUESTION 8-12, REFER TO FIGURE 6-62 OF THE TEXT.

8-12. What quantity is represented by the mechanical position of the rotor of resolver BR-1?

1. Range (R)
2. Height (Rv)
3. Range (Rh)
4. Elevation (E)

8-13. The (a) inputs and (b) output(s) of a resolver used for the composition of a vector are of what type?

1. (a) One electrical and one mechanical
   (b) one mechanical
2. (a) One electrical and one mechanical
   (b) two electrical
3. (a) Two electrical
   (b) one electrical and one mechanical
4. (a) Two electrical and one mechanical
   (b) two electrical

8-14. The signal to the servo in a resolver servosystem for solving vector composition problems comes from which of the following sources?

1. One of the windings of the resolver stator
2. Both of the windings of the resolver stator
3. One of the windings of the resolver rotor
4. Both of the windings of the resolver rotor

IN ANSWERING QUESTIONS 8-15 AND 8-16, REFER TO FIGURE 6-63 OF THE TEXT.

8-15. The target course (Ct) vector computed by the resolver is represented by the

1. mechanical position of the rotor
2. mechanical position of the stator
3. magnitude of the R1 voltage
4. magnitude of the R2 voltage

8-16. Target speed DMh computed by the resolver is represented by the

1. mechanical position of the rotor
2. mechanical position of the stator
3. magnitude of the R1 voltage
4. magnitude of the R2 voltage

8-17. A resolver used to rotate coordinates from one axis system to another has (a) what type(s) of inputs and (b) what type(s) of output(s)?

1. (a) One electrical and one mechanical
   (b) one mechanical
2. (a) One electrical and one mechanical
   (b) two electrical
3. (a) Two electrical
   (b) one electrical and one mechanical
4. (a) Two electrical and one mechanical
   (b) two electrical

IN ANSWERING QUESTION 8-18, REFER TO FIGURE 6-67 OF THE TEXT.

8-18. What trigonometric functions are solved by resolvers B1 and B2?

1. B1 - resolution of a vector,
   B2 - rotation of coordinates
2. B1 - rotation of coordinates,
   B2 - composition of a vector
3. B1 - composition of a vector,
   B2 - resolution of a vector
4. B1 - composition of a vector,
   B2 - rotation of coordinates

8-19. What parts of a right triangle are represented by the voltage inputs to the stator and rotor circuits of an inverse sine resolver loop?

1. Stator - angle θ, rotor - hypotenuse
2. Stator - hypotenuse, rotor - side opposite of angle θ
3. Stator - angle θ, rotor - either side
4. Stator - hypotenuse, rotor - side adjacent to angle θ

8-20. What parts of a right triangle are represented by the voltage inputs to the stator and rotor circuits of an inverse cosine resolver loop?

1. Stator - angle θ, rotor - hypotenuse
2. Stator - hypotenuse, rotor - side opposite to angle θ
3. Stator - angle θ, rotor - either side
4. Stator - hypotenuse, rotor - side adjacent to angle θ

Learning Objective: Indicate the procedure for determining the rate of change (acceleration and deceleration) of input and output data of the analog computer.

8-21. A rate computing loop establishes the rate of change of its input by which of the following methods?

1. Differentiation
2. Integration
3. Resolution
4. Summation

8-22. In a Cartesian coordinate system, the future target position is predicted by establishing which of the following quantities?

1. DMhx
2. DMhy
3. DMv
4. Each of the above

IN ANSWERING QUESTIONS 8-23 AND 8-24, REFER TO FIGURE 6-70 OF THE TEXT.

8-23. The rate loop shown establishes the rate of change of the target position along which of the following coordinates?

1. North-south
2. East-west
3. Vertical (target height)
4. Horizontal (horizontal range)

8-24. The output voltage from R2 provides a negative feedback voltage to cancel the

1. a.c. input to the d.c. amplifier
2. a.c. input to the a.c. amplifier
3. d.c. input to the d.c. amplifier
4. d.c. input to the a.c. amplifier

Learning Objective: Identify the major elements and operating principles of digital computers.

8-25. A computer may be divided into which of the following major sections?

1. Mechanical, electrical and digital
2. Input, accept, and reject
3. Input, processing, and output
4. Accept, operate, and reject

8-26. In fire control applications, what is the most common digital computer input device?

1. Analog-to-digital converter
2. Typewriter keyboard
3. Punched cards
4. Paper tape

8-27. What unit of a computer directs all operations performed within the computer?

1. Input
2. Memory
3. Control
4. Arithmetic

8-28. Logical decisions in a digital computer are accomplished in the

1. control unit
2. arithmetic unit
3. input unit
4. output unit

8-29. The memory unit of a digital computer is used to store which of the following data?

1. Computation data
2. Program instructions
3. Intermediate and final results
4. Each of the above

8-30. An address, as used in a digital computer, is used to identify which of the following features?

1. Input format
2. Output location
3. Memory storage location
4. Control method

8-31. Some computers are designed for serial feeding rather than parallel feeding, because in serial-fed computers,

1. error potential is less
2. simpler circuitry may be used
3. faster response to each information bit is realized
4. instructions may precede information data

8-32. The storage capacity of a register is determined by which of the following factors?

1. The number of flip-flops
2. Access time
3. The control unit
4. The program

8-33. When associated with the proper circuitry, a register is capable of performing which of the following functions?

1. Serial-to-parallel conversion
2. Shift left or right
3. Accumulate sums
4. Each of the above

8-34. A total of how many bits of information can be stored in a flip-flop?

1. One
2. Two
3. Three
4. Four

8-35. The time required to write in or read out information from storage is identified by which of the following terms?

1. Run time
2. Access time
3. Cyclic access
4. Random access

Learning Objective: Identify the major steps in preparing a problem for solution by a computer.

8-36. A computer performs operations in a sequence that is determined initially by

1. a programmer
2. an input unit
3. an arithmetic unit
4. the logic circuits

8-37. The reduction of a problem into a language acceptable to a computer is accomplished during which of the following preliminary actions?

1. Numerical analysis
2. Flow charting
3. Loading
4. Programming

8-38. Computer flow charts are used for which of the following?

1. To indicate the sequence of computer operations
2. To plan memory allocations
3. To aid in performing computer maintenance
4. Each of the above

8-39. Switches, tubes, and transistors are especially adaptable for use with the binary numbering system for which of the following reasons?

1. Simplicity of operation
2. Bistable operation
3. Stable operation
4. Monostable operation

8-40. A total of how many basic types of computer words is used?

1. Five
2. Two
3. Three
4. Four

IN ANSWERING QUESTION 8-41, REFER TO FIGURE 7-5A OF THE TEXT.

8-41. What bits of an instruction word contain the memory address?

1. 1 and 5
2. 0 and 6
3. 1 through 6
4. 7 through 18

8-42. What bits of an instruction word must be zero in no-address use?

1. 1 and 5
2. 1 through 5
3. 0 and 6
4. 0 through 6

8-43. What portion of a no-address word would contain the number of places a number is to be shifted?

1. First
2. Second
3. Third
4. Fourth

8-44. What is indicated by the first bit of an information word?

1. Type of information contained
2. Sign of the number
3. Mathematical operation to be performed
4. Address of the word

8-45. Before negative numbers are used in a computer, they are converted to which of the following forms?

1. One's complement
2. Two's complement
3. Gray code
4. Binary coded decimal (BCD)

TO ANSWER QUESTIONS 8-46 THROUGH 8-48, SELECT FROM COLUMN B THE TYPE OF PROGRAM MODIFICATION THAT IS USED TO PERFORM THE FUNCTION IN COLUMN A.

	A. FUNCTIONS	B. TYPES
8-46.	To change the address portion of an instruction word by the contents of the B-register	1. Indirect address 2. No-address
8-47.	To alter the address of an instruction by the address of an instruction word from memory	3. B-modify 4. Trap or interrupt mode
8-48.	To interrupt the computer program in progress to perform another operation	

TO ANSWER QUESTIONS 8-49 THROUGH 8-51, SELECT FROM COLUMN B THE TYPE OF CODE THAT REPRESENTS THE CATEGORIES LISTED IN COLUMN A.

	A. CATEGORIES	B. CODES
8-49.	Regularly weighted	1. XVII
8-50.	Arbitrarily weighted	2. 0101
8-51.	Nonweighted	3. 6442
		4. 8642

8-52. Express the decimal number 54 as a binary-coded decimal number.

1. 0101101
2. 0110110
3. 0100 0101
4. 0101 0100

8-53. The two-out-of-five code that is used as the basis for error checks has which of the following characteristics in each code group?

1. At least two 1's
2. Exactly two 1's
3. Seven bits
4. Two parts

8-54. A very stable oscillator that produces pulses of fixed frequency is used in a digital computer to provide which of the following functions?

1. Produce pulses for shift registers
2. Control for the memory circuits
3. Timing distinction between bits
4. Timing distinction between control and memory

Learning Objective: Identify the principles of data conversion as used in digital computers.

8-55. An encoder or converter is a device used with a digital computer to

1. convert decimal numbers into decimal voltages
2. convert decimal numbers into binary numbers
3. convert binary numbers into decimal numbers
4. convert analog information into digital information

8-56. A signal converter is capable of converting which of the following analog signals into a digital form?

1. Synchro signals
2. D.C. voltage
3. A.C. voltage
4. Each of the above

8-57. Which of the following devices is commonly used to indicate the number of shaft revolutions or a shaft position?

1. A voltage readout meter
2. A mechanical counter
3. A synchro
4. A resolver

IN ANSWERING QUESTIONS 8-58 AND 8-59, REFER TO FIGURE 7-7 OF THE TEXT.

8-58. What total number of inputs is applied to the comparator?

1. One
2. Two
3. Three
4. Four

8-59. The number of pulses accumulated on the counter during comparison is proportional to which of the following characteristics of the analog input voltage?

1. Phase
2. Duration
3. Amplitude
4. Shape

8-60. What is the primary advantage of the coding tube method of analog-to-digital conversion?

1. High speed
2. Accuracy
3. Simplicity
4. Small size

IN ANSWERING 8-61, REFER TO FIGURE 7-9 OF THE TEXT.

8-61. Which of the following signals causes the servomotor to rotate?

1. The input
2. The output
3. The error
4. The analog

IN ANSWERING 8-62, REFER TO FIGURE 7-10 OF THE TEXT.

8-62. A current that is a function of the number of branches in a conducting state flows through which of the following resistors?

1. R_1
2. R_2
3. R_3
4. R_L

IN ANSWERING QUESTION 8-63, REFER TO FIGURE 7-11 OF THE TEXT.

8-63. The increase in amplifier gain is proportional to which of the following circuit characteristics?

1. Feedback resistance
2. Input resistance
3. Output resistance
4. Amplifier resistance

8-64. In a digilog transistor switch circuit, what causes the switch to open or close?

1. The analog signal
2. The digital signal
3. The feedback resistance
4. The output resistance

8-65. In the digilog converter, how many transistor switches are required for each digital word?

1. One per word
2. Two per word
3. One for each digit of the word
4. Two for each digit of the word

8-66. What maximum number of voltage levels are available from a 4-switch digilog?

1. 4
2. 6
3. 8
4. 16

Learning Objective: Identify the methods of checking digital computers for operational accuracy.

8-67. By what method are digital computers checked?

1. By running a set of tests and measuring the results on a special test set
2. By measuring waveforms with an oscilloscope
3. By running a test program using the computer circuits
4. By measuring the input and output voltages with a voltmeter

8-68. What types of programs are used (a) to localize a malfunction in the computer and (b) to check the reliability of the computer circuits?

1. (a) Diagnostic (b) maintenance
2. (a) Maintenance (b) normal
3. (a) Normal (b) diagnostic
4. (a) Maintenance (b) diagnostic

Assignment 9

Directors and Antennas; Fire Control Radar

Textbook Assignment: FTG 3 & 2, NAVEDTRA 10207-B; pages 8-1 through 9-4

Learning Objective: Identify the basic functions and operating principles of directors and antennas.

9-1. Which of the following advantages is gained by mounting a director as high as practical aboard ship?

1. It moves the los above the gun blast
2. It moves the los above the sea spray
3. It extends the range of the los
4. Each of the above

9-2. The primary function of a gun director is to establish and maintain

1. stabilization of the lof
2. stabilization of the los
3. the los on target
4. the lof on target

9-3. The entire rotating structure of a director is moved to measure which of the following quantities?

1. Range
2. Director elevation
3. Director train
4. Each of the above

IN ANSWERING QUESTIONS 9-4 AND 9-5, REFER TO FIGURE 8-5 OF THE TEXT.

9-4. What is the effect of level on the cross hairs of a telescope pointing at a target?

1. Cross hairs are rotated around the los only
2. Cross hairs are displaced vertically only
3. Cross hairs are displaced horizontally only
4. Cross hairs are displaced horizontally and vertically and are rotated around the los

9-5. What is the effect of crosslevel on the cross hairs of a telescope pointing at a target?

1. Cross hairs are rotated around the los only
2. Cross hairs are displaced vertically only
3. Cross hairs are displaced horizontally only
4. Cross hairs are displaced horizontally and vertically and are rotated around the los

9-6. In what plane is a director's elevation axis maintained by crosslevel?

1. Deck
2. Horizontal
3. Normal
4. Slant

9-7. In a fire control system, the mode control switching circuits affect the mode of operation of which of the following components?

1. The computer
2. The director
3. The radar
4. Each of the above

9-8. Which of the following conditions must be met in order to place a director in the standby mode?

1. The power brakes are off
2. Plate supply voltage to the electronic amplifiers is energized
3. Filament voltage to the electronic amplifiers is energized
4. High voltages to the drive motors are energized

9-9. In what mode of operation are directors self-synchronous?

1. Standby
2. Track
3. Designation
4. Test

9-10. A fire control system is shifted to the track mode when the director has acquired the

1. TDS signal
2. target
3. correct speed
4. computer signal

IN ANSWERING QUESTIONS 9-11 THROUGH 9-13, REFER TO FIGURE 8-8 OF THE TEXT.

9-11. In optical control, the function of error detection for the train tracking loop is performed by the

1. computer
2. radar
3. trainer
4. director

9-12. In full automatic control, the function of error detection for the train tracking loop is performed by the

1. computer
2. radar
3. trainer
4. pointer

9-13. The tracking system is in full automatic control. The input to the director power drive amplifier is the algebraic sum of the signals from the

1. computer and handwheel
2. handwheel and radar
3. radar and computer
4. computer, handwheel, and radar

9-14. In the local mode of system operation, where can the control signals for the director's power drives originate?

1. The radar console
2. The slew sight
3. The pointer's and trainer's handwheels
4. Each of the above

Learning Objective: Identify the basic operating principles of an amplidyne power drive.

IN ANSWERING QUESTIONS 9-15 AND 9-16, REFER TO FIGURE 8-9 OF THE TEXT.

9-15. Which unit of the amplidyne system serves the same function as the comparison device in a servosystem?

1. Amplifier
2. Amplidyne generator
3. Synchro generator
4. Synchro control transformer

9-16. Which unit of the amplidyne system provides the control currents for the amplidyne generator?

1. Amplifier
2. Power motor
3. Synchro generator
4. Synchro control transformer

9-17. An amplidyne generator has a total of (a) how many control windings and (b) how are these windings wound?

1. (a) One (b) clockwise
2. (a) One (b) counterclockwise
3. (a) Two (b) aiding
4. (a) Two (b) opposing

IN ANSWERING QUESTION 9-18, REFER TO FIGURE 8-10 OF THE TEXT.

9-18. When an error signal is applied to the amplifier unit, which quantity in the system changes?

1. The direction of rotation of the amplidyne generator
2. The current in the armature windings of the amplidyne generator
3. The speed of rotation of the amplidyne generator
4. The magnetic field of the generator drive motor

9-19. The function of the compensating winding in an amplidyne generator is to compensate for the

1. current in the control field windings of the generator
2. speed variations in the generator drive motor
3. quadrature field in the generator
4. magnetic field in the generator produced by the load current

9-20. In a permanent-magnet d.c. motor, how is the magnetic field provided?

1. Permanent magnets built into the rotor
2. Permanent magnets built into the stator
3. A steady d.c. current applied to the stator windings
4. A varying d.c. current applied to the stator windings

9-21. What is the source of current for the armature of an amplidyne servosystem drive motor?

1. The exciter generator
2. The amplifier
3. The amplidyne generator
4. The load

9-22. What methods are used to change (a) the direction of rotation and (b) the speed of an amplidyne servosystem drive motor?

1. (a) Reversing the direction of amplidyne rotation
   (b) Changing the amplitude of the amplidyne output
2. (a) Reversing the direction of amplidyne rotation
   (b) changing the speed of the amplidyne
3. (a) Reversing the excitation polarity of the drive motor
   (b) changing the amplitude of the amplidyne output
4. (a) Reversing the excitation polarity of the drive motor
   (b) changing the speed of the amplidyne

TO ANSWER QUESTIONS 9-23 THROUGH 9-25, SELECT FROM COLUMN B THE TYPE OF STABILIZING VOLTAGE, AS USED IN A TRAIN AMPLIDYNE FOLLOWUP SYSTEM, THAT IS OBTAINED FROM THE SOURCE LISTED IN COLUMN A.

	A. SOURCES	B. VOLTAGES
9-23.	D.c. tachometer generator	1. Low Frequency
9-24.	Series field of the drive motor	2. Speed
		3. Jitter
9-25.	Quadrature winding of the amplidyne	4. Current

IN ANSWERING QUESTIONS 9-26 THROUGH 9-30, REFER TO FIGURE 8-11 OF THE TEXT.

TO ANSWER QUESTIONS 9-26 THROUGH 9-28, SELECT FROM COLUMN B THE COMPONENT OF THE TRAIN STABILIZING CIRCUIT THAT IS USED FOR THE PURPOSE LISTED IN COLUMN A.

	A. PURPOSES	B. COMPONENTS
9-26.	Provides a means of adjusting the percentage of current stabilizing voltage used in the amplifier	1. R_{15} 2. R_{16} 3. R_{17}
9-27.	Provides a means of adjusting the percentage of jitter stabilizing voltage used in the amplifier	4. R_{18}
9-28.	Provides a means of adjusting the percentage of speed stabilizing voltage used in the amplifier	

9-29. Which of the following elements of the train stabilizing circuit prevents low frequency components of the total stabilizing voltage from entering the converter circuit?

1. R_1 and R_{13}
2. C_1 and C_6
3. C_2 and C_6
4. C_7 and C_8

9-30. What is the phase relationship between the error signal and the stabilizing voltages in the circuit?

1. 0°
2. 90°
3. 120°
4. 180°

IN ANSWERING QUESTIONS 9-31 THROUGH 9-33, REFER TO FIGURE 8-12 OF THE TEXT.

9-31. The error signal in the train circuit is supplied to the synchronizing circuit of the amplifier through which of the following transformers?

1. T_6
2. T_3
3. T_2
4. T_1

9-32. The error signal in the train circuit is supplied to the converter stage of the amplifier through which of the following transformers?

1. T_1
2. T_2
3. T_3
4. T_6

9-33. Which components of the train circuit provide "push-pull" amplification?

1. V_1 and V_2
2. V_2 and V_3
3. V_3 and V_4
4. V_4 and V_5

9-34. What is the source of the operating power for the train motor in a gun director?

1. The amplifier
2. The speed control transformer
3. The amplidyne generator
4. The statilizing tachometer

IN ANSWERING QUESTIONS 9-35 AND 9-36, REFER TO FIGURE 8-13 OF THE TEXT.

9-35. The output voltage of the converter circuit is the result of what type of comparison?

1. Phase and amplitude comparison of two a.c. voltages
2. Amplitude comparison of two a.c. error voltages
3. Amplitude comparison of two d.c. voltages
4. Frequency comparison of two a.c. voltages

9-36. Which components of the train converter circuit control the bias for tubes V1 and V2?

1. R_3 and R_4
2. C_1 and C_2
3. C_3 and C_4
4. R_{14} and R_{20}

IN ANSWERING QUESTIONS 9-37 AND 9-38, REFER TO FIGURE 8-14 OF THE TEXT.

9-37. The direct current flow through resistors R_3 and R_4 affects the operation of tubes V_3 and V_4 in the output stage by

1. stabilizing the d.c. plate voltages of the tubes
2. varying the grid bias of the tubes
3. equalizing the plate currents of the tubes
4. stabilizing the d.c. screen grid voltages of the tubes

9-38. The amplidyne connected to the output state produces an output under which of the following conditions?

1. Unequal plate currents through tubes V_3 and V_4
2. Equal plate currents through tubes V_3 and V_4
3. Equal bias voltages applied to tubes V_3 and V_4
4. Equal voltage drops across resistors R_7 and R_8

9-39. What is the function of the synchronizing circuit in the train drive of a gun director?

1. To control the rate of change of the load on the amplidyne generator
2. To remove hunt and jitter effects from the director movement
3. To control the rate of movement of the director for large error signals
4. To generate the error signals that control the director movement

9-40. A train synchronizing circuit, using a 36-speed input, can synchronize at a total of how many positions with what degree of separation?

1. 18 positions each 20° apart
2. 36 positions each 10° apart
3. 72 positions each 5° apart
4. 144 positions each 2 1/2° apart

IN ANSWERING QUESTIONS 9-41 AND 9-42, REFER TO FIGURE 8-12 OF THE TEXT.

9-41. Closing the K_1 contacts at points c in the train circuits affects V_3 and V_4 by making the

1. plates less positive
2. plates less negative
3. grids less positive
4. grids less negative

9-42. Closing the K_1 contacts at point b in the train circuit affects V_1 and V_2 by making the

1. plates less positive
2. plates less negative
3. grids less positive
4. grids less negative

IN ANSWERING QUESTIONS 9-43 AND 9-44, REFER TO FIGURE 8-15 OF THE TEXT.

9-43. For which of the following train error signals will relay K_1 be deenergized?

1. 45 minutes
2. 1 degree
3. 1 degree, 15 minutes
4. 1 degree, 45 minutes

9-44. Which of the following casualties has probably occurred if K_1 of the train synchronizing circuit closes prematurely?

1. V_1 or V_2 weak
2. C_3 or C_4 defective
3. R_{19} out of adjustment
4. R_{14} out of adjustment

Learning Objective: Identify the basic principles of radar and the classes of fire control radar.

9-45. Radio-frequency (rf) energy makes radar practical as a data-sensing element because it has which of the following properties?

1. It travels in a straight line
2. Reflected, it travels a reciprocal path to that of radiated energy
3. It travels at a constant velocity which is independent of its energy level
4. Each of the above

QUESTIONS 9-46 AND 9-47 ARE TO BE JUDGED TRUE OR FALSE.

9-46. Radar range is measured by the time it takes energy to travel from the radar antenna to target and back to the radar antenna again.

1. True
2. False

9-47. Because rf waves must travel from source to target and back again before echo is detected, we can say target range is twice the total distance of the traveled signal.

1. True
2. False

9-48. How many microseconds are equivalent to one second?

1. 10
2. 1,000
3. 100,000
4. 1,000,000

9-49. The range to a target aircraft is 60 nautical miles, and the echo signal has reached a point midway between the antenna and the target. Approximately how many microseconds have elapsed from the time the radar signal was transmitted until it reached its present position?

1. 120
2. 350
3. 550
4. 756

9-50. Assume that it takes 123.6 microseconds for rf energy to reach a target and return to the point of origin. Approximately how far is the target from the point of origin?

1. 5 nautical miles
2. 10 nautical miles
3. 20 nautical miles
4. 30 nautical miles

9-51. What is meant by the pulse repetition rate (pdr) of a radar transmitter?

1. The frequency of the transmitted waves
2. The rate at which the transmitter sends out pulses
3. The length of time the pulse is sent out by the transmitter
4. The length of time between pulses sent out by the transmitter

9-52. By what method do fire control radars determine the bearing and elevation of an air target?

1. Dividing the number of microseconds between transmission and echo return by the constant 12.36
2. Multiplying the number of microseconds between transmission and echo return by the constant 12.36
3. Comparison of echo frequencies
4. Comparison of echo strength

9-53. In a scanning system, the amplitude of a target echo depends on which of the following factors?

1. Scanning rate of the radar beam
2. Frequency of the transmitted radar pulse
3. Position of the target with respect to the axis of the radar beam
4. Tilt angle of the radar antenna with respect to the horizon

9-54. What factors are considered when assigning a classification to a fire control radar?

1. The method of transmission and modulation
2. The frequency or wavelength
3. The general use and method of scanning
4. Each of the above

9-55. The pulse repetition rate (prr) of a radar set determines

1. peak power of the set
2. antenna rotation rate
3. size of the target
4. usable range of the radar

9-56. A cw radar detects a moving target by measuring which of the following quantities?

1. The energy contained in the reflected signal
2. The energy difference between the transmitted and reflected signals
3. The frequency difference between the transmitted and reflected signals
4. The phase difference between two reflection signal components

9-57. Which of the following types of radar is designed to make use of the doppler effect?

1. Continuous-wave
2. Frequency modulation
3. Pulse modulation
4. Single sideband

9-58. Continuous-wave radar is useful for the direct indication of target

1. range
2. range rate
3. elevation
4. size

9-59. What information concerning a target is cw radar incapable of detecting?

1. Bearing
2. Velocity
3. Range
4. Elevation

9-60. Signals transmitted by a conventional pulse radar differ from the signals transmitted by a pulse-doppler radar in that the conventional signals have a

1. longer pulse length and a higher prr
2. shorter pulse length and a lower prr
3. longer pulse length and a lower prr
4. shorter pulse length and a higher prr

9-61. What advantage does pulse-doppler radar have over conventional radar in target detection?

1. Better frequency stability
2. Shorter pulse length
3. Less subject to noise and interference
4. More accurate range measurement

Learning Objective: State the functions of radar in Fire Control systems.

9-62. Detecting and tracking surface and air targets, guiding a missile to a target, and operating with a radar beacon are some of the functions of a/an

1. air search radar
2. fire control radar
3. identification radar
4. surface search radar

9-63. What factor is established by the los?

1. Ownship future position
2. Target present position
3. Target range
4. Ownship speed

9-64. The operation of a fire control radar target tracking system may be compared to the operation of which of the following types of system?

1. Servo
2. Data transmission
3. Synchro
4. Resolver

Assignment 10

Fire Control Radar (Continued)

Textbook Assignment: FTG 3 & 2, NAVEDTRA 10207-B; pages 9-5 through 9-35

Learning Objective: Identify the functional sections of a fire control radar.

10-1. Which unit of a radar system determines the order in which all other units of the radar operate?

1. The automatic tracking system
2. The receiving system
3. The timing system
4. The transmitting system

10-2. In a radar system using an oscillator circuit that produces a sine-wave voltage with a frequency of 163.88 kHz, approximately how many microseconds does it take for a radar pulse to reach a target 12,000 yards away and return at an echo to the radar?

1. 36.6
2. 54.8
3. 73.2
4. 91.4

10-3. The master oscillator produces an oscillation equal in frequency to which of the following pulses?

1. The main timing pulse
2. The modulator pulse
3. The prr
4. All of the above

10-4. The reference marks are fed into which of the following circuits?

1. The first reference blocking oscillator
2. The prr blocking oscillator
3. The first reference coincidence amplifier
4. The first and second reference coincidence amplifier

TO ANSWER QUESTIONS 10-5 THROUGH 10-7, SELECT FROM COLUMN B THE PULSE THAT PERFORMS THE FUNCTION LISTED IN COLUMN A.

	A. FUNCTIONS	B. PULSES
10-5.	To set a point from which time is measured	1. Sync pulse
		2. Reference marks
10-6.	To set a point in time from which A sweeps are started	3. Mod trigger
		4. Modulator pulse
10-7.	To set the point in time for zero range from which range is measured	

Learning Objective: Identify the principles of operation of the fire control radar transmitting system.

10-8. Fire control radars transmit within which of the following frequency ranges?

1. 1,000 hertz to 3,500 hertz
2. 1,550 hertz to 10,900 hertz
3. 1,550 kHz to 10,900 kHz
4. 1,550 MHz to 10,900 MHz

10-9. Fire control radars employ pulse repetition frequencies in the range of

1. 1,000 hertz to 3,500 hertz
2. 1,550 hertz to 10,900 hertz
3. 1,550 kHz to 10,900 kHz
4. 1,550 MHz to 10,900 MHz

10-10. In a fire control radar, the output pulse of the modulator section of the transmitter has an (a) amplitude and a (b) duration of

1. (a) 5,000 to 10,000 volts
   (b) 10 microseconds
2. (a) 10,000 to 15,000 volts
   (b) 5 microseconds
3. (a) 10,000 to 20,000 volts
   (b) 1 microsecond
4. (a) 10,000 to 30,000 volts
   (b) .5 microsecond or less

10-11. To what element is the voltage that triggers a radar magnetron normally applied?

1. Cathode
2. Grid
3. Plate
4. Filament

10-12. What determines the oscillation frequency of a magnetron?

1. The pulse frequency
2. The cavity size
3. The magnetic field
4. The anode size

10-13. Which of the following conditions must be met to realize oscillation within a basic klystron?

1. The energy required for bunching must be greater than the energy applied to the catcher
2. The energy required for bunching is equal to, but 180° out of phase with the energy applied to the catcher
3. The energy required for bunching must be less than the energy applied to the catcher
4. The energy required for bunching must be exactly the same as the energy applied to the catcher

10-14. Absorption of rf energy from the passing electrons by the catcher grids in a basic klystron occurs because of the

1. bunching effect of the electrons caused by the oscillator's decelerating half cycle
2. decelerating field set up in the drift space
3. bunching effect of the electrons caused by the oscillator's accelerating half cycle
4. accelerating field set up by the long transit time of the electrons

10-15. The electron beam in a twt is accelerated by high potentials on which of the following components?

1. The cathode and helix
2. The helix and collector
3. The collector and beam forming anode
4. The cathode and beam forming anode

IN ANSWERING QUESTION 10-16, REFER TO FIGURE 9-8 OF THE TEXT.

10-16. What component of the twt reduces oscillations caused by backward reflections within the tube?

1. The shield
2. The modulator grid
3. The single wire helix
4. The lossy-wire attenuator

10-17. Which of the following actions is the primary function of the modulator?

1. Applying high voltage pulses to the magnetron
2. Supplying transmitter timing pulses
3. Supplying receiver timing pulses
4. Applying rf pulses to the antenna

QUESTION 10-18 IS TO BE JUDGED TRUE OR FALSE.

10-18. The driver hard-tube modulator uses a lumped-constant, transmission line, pulse-forming network as both the energy storage driver and the pulse-shaping element.

1. True
2. False

10-19. The modulator switching device must meet which of the following criteria?

1. High prr frequency
2. High current flow
3. Accurate on/off control
4. All of the above

IN ANSWERING QUESTION 10-20, REFER TO FIGURE 9-11 OF THE TEXT.

10-20. What causes the thyratron to conduct?

1. The source voltage
2. The driver trigger
3. The pfn charge
4. The charging diode output

QUESTION 10-21 IS TO BE JUDGED TRUE OR FALSE.

10-21. A transmitter pulse transformer is an impedance matching device.

1. True
2. False

10-22. An excessive amount of interwinding capacitance in a pulse transformer would produce which of the following effects?

1. Secondary overload
2. High core currents
3. High-frequency oscillations
4. Primary overload

10-23. A transformer winding made of two insulated conductors wound side by side in order to receive exactly the same voltage is characteristic of which of the following design configurations?

1. Delta wound
2. Wye wound
3. Magnetic core wound
4. Bifilar wound

10-24. By what means is the transmitter output pulse transferred to the antenna?

1. Coaxial cable
2. Two-wire transmission
3. Waveguide
4. Atr tube

10-25. Which of the following conditions will result in the most efficient transfer of energy into or out of a waveguide?

1. The resistance of all elements of the line is matched
2. The impedance of all elements of the line is matched
3. The inductance of all elements of the line is matched
4. The capacitance of all elements of the line is matched

10-26. Which of the following numbers represents the most efficient standing wave ratio?

1. One
2. Two
3. Three
4. Four

10-27. The function of the duplexer is that of a switch which connects the antenna to the

1. tr tube during periods of transmission and to the magnetron during periods of reception
2. tr tube during periods of transmission and to the receiver during periods of reception
3. magnetron during periods of transmission and to the receiver during periods of reception
4. magnetron during periods of transmission and to the tr tube during periods of reception

10-28. A defective tr tube in a radar set will most likely cause damage to which of the following components?

1. Receiver crystals
2. Waveguide
3. Magnetron
4. Local oscillator

10-29. The high amplitude pip that appears at the beginning of the sweep of an A-scope is the result of the

1. long persistence of the scope tube
2. delay of the electron beam as it rests before starting its sweep
3. transmitter pulse
4. target echo

10-30. The speed and sensitivity of tr tube operation are increased by the use of a

1. half-wave coupling section
2. quarter-wave coupling section
3. keep-alive voltage
4. slotted line section

10-31. A defective atr tube in a radar set will most likely cause which of the following results?

1. Damage to the receiver
2. Damage to the transmitter
3. A loss of returned rf energy to the transmitter
4. A reduction of returned rf energy to the receiver

Learning Objective: Identify the principles of operation of fire control radar antennas.

10-32. Which unit of a radar set controls beam width and radiates the rf energy into space?

1. The antenna
2. The receiver
3. The transmitter
4. The synchronizer

10-33. Which of the following actions permit(s) a parabolic reflector to produce a narrow rf beam?

1. Spherical wavefronts from the antenna are changed to plane wavefronts by the reflector
2. Energy from the feedhorn is concentrated into a circular beam by the reflector
3. Striking and reflecting rays make equal angles with the reflector
4. All of the above

IN ANSWERING QUESTION 10-34, REFER TO FIGURE 9-20A OF THE TEXT.

10-34. At what point should a feedhorn radiator be placed?

1. The focal point
2. Any point along the focal axis
3. On the reflector
4. Any point in front of the reflector

10-35. What, if anything, is the difference between the transmitting and receiving patterns of an antenna system?

1. The transmitting pattern has a higher frequency than the receiving pattern
2. The transmitting pattern has a lower frequency than the receiving pattern
3. The transmitting and receiving patterns do not have the same focal point
4. Nothing, they are basically the same

10-36. The process of searching for a target and determining its position by an antenna system is accomplished by which of the following methods?

1. Modulation of the beam
2. Directivity of the reflector
3. Scanning
4. All of the above

QUESTION 10-37 IS TO BE JUDGED TRUE OR FALSE.

10-37. During conical scanning, the axis of both the horizontal and vertical position of the waveguide antenna must remain unchanged.

1. True
2. False

10-38. In a conically scanned radar, what information does the angle error director use to compute the direction and amount of correction for continuous target tracking?

1. Beam position relative to scan axis only
2. Magnitude of received target signal only
3. Beam position relative to scan axis and magnitude of received target signal only
4. Magnitude of received target signal, beam position relative to scan axis and return signal polarity of the highest and lowest part of the scan pattern

10-39. What determines the amount of total return energy received by each of the four horns in a monopulse radar?

1. The microwave lens of the antenna system
2. The target position relative to the beam axis
3. The amount of energy being transmitted out of each horn
4. All of the above

10-40. In a monopulse radar, what is the phase difference between an error signal that represents a pure error in train and an error signal that represents a pure effort in elevation?

1. 0°
2. 45°
3. 90°
4. 180°

Learning Objective: Explain the theory of operation of the receiver system of a fire control radar.

10-41. Which unit of a radar set converts echo signals to video signals?

1. The antenna
2. The receiver
3. The transmitter
4. The synchronizer

10-42. Receiver sensitivity is largely limited by which of the following factors?

1. The gain of the IF stages only
2. The echo-signal amplification
3. The noise produced in receiver circuits
4. The echo-signal selectivity

10-43. What stage in a high-frequency radar receiver changes the returned rf pulse to an intermediate frequency?

1. The converter
2. The IF amplifier
3. The mixer
4. The second detector

10-44. What is the function of the second detector of a radar receiver?

1. To generate a square wave of sufficient amplitude to trigger the indicator sweep circuits
2. To remove the AF component of the received signal
3. To remove the video modulation from the carrier
4. To trigger the multivibrator in the timer

10-45. The afc system keeps the radar receiver tuned to which of the following frequencies?

1. The rf oscillator frequency
2. The returned echo frequency
3. The intermediate frequency
4. The transmitted frequency

10-46. The automatic frequency control (afc) provides the receiver with a constant IF by controlling the output of the

1. local oscillator
2. magnetron
3. modulator
4. duplexer

10-47. A change in the local oscillator frequency would cause which of the following operational changes?

1. Greater receiver gain
2. Less receiver gain
3. More transmitter power
4. Less transmitter power

10-48. What are reflex klystron tubes used for in superheterodyne receivers?

1. Rf amplifiers
2. Local oscillators
3. Mixers
4. Detectors

10-49. Which of the following components are the primary construction elements of a balanced mixer?

1. Crystal diodes and sections of the waveguide
2. An electron-tube and its circuit
3. A transistor and its circuit
4. A capacitor-resistor network

10-50. What portion of the radar receiver determines the effective band width?

1. The mixer
2. The rf amplifier
3. The IF amplifier
4. The video detector

10-51. In which portion of the radar receiver is noise generation most critical?

1. The mixer
2. The IF amplifier first stage
3. The rf amplifier
4. The video detector

10-52. What type of signal is the output of the detector circuit?

1. IF
2. Rf
3. Afc
4. Video

Learning Objective: Identify the principles of operation of radar indicators.

10-53. What is used to ensure that the video display starts at the same position on the scope for each transmitted pulse, regardless of the radar's prr?

1. The A-trigger
2. The mod-trigger
3. The sync pulse
4. The time delay between A-trigger and mod-trigger

10-54. How is the duration of the unblank voltage to the indicator scopes determined?

1. By the length of the range sweep
2. By the pulse repetition rate of the radar
3. By the position of the movable reference marks
4. By the type of scope presentation desired

10-55. The range step on a precision sweep of a fire control radar remains stationary on the indicator scope because the

1. precision sweep is triggered by the A-trigger
2. range step is triggered by the mod-trigger
3. precision sweep is triggered by the movable range pulse
4. range step is triggered by the movable range pulse

10-56. What effect, if any, will a defective angle sweep generator have on a fire control radar?

1. Loss of A-sweep presentation
2. Loss of B-type presentation
3. Loss of prr
4. None

10-57. The A-video is presented on the radar scope as a

1. blanked spot
2. bright spot
3. horizontal deflection of the sweep
4. vertical deflection of the sweep

10-58. The B-video is presented on the radar scope as a

1. blanked spot
2. bright spot
3. horizontal deflection of the sweep
4. vertical deflection of the sweep

10-59. What type of wave form is the output of the phantastron circuit and what part of this wave represents the zero reference?

1. The leading edge of a square wave
2. The trailing edge of a square wave
3. All of a positive sawtooth wave
4. All of a negative sawtooth wave

10-60. The shape and duration of the output pulse of the coarse delay oscillator is determined by which of the following factors?

1. The input signal
2. The zero reference time of the ranging system
3. The circuit components of the coarse delay oscillator
4. The pulse repetition rate of the radar

10-61. How is the width of the phantastron gate controlled?

1. By the prr of the radar
2. By the trigger from the synchronizing system
3. By the range potentiometer
4. By the afc circuits

10-62. What, if anything, is the major difference between the reference marks produced by a synchronizer system and the fine delay circuit of a range system?

1. The reference marks from the range system are movable
2. The reference marks from the synchronizer system are movable
3. The prr of the reference marks is not the same
4. Nothing; there is no difference

10-63. If you rotate a vari-phase capacitor one fourth of a turn, how many yards of range does this represent?

1. 250
2. 500
3. 750
4. 1000

10-64. What two radar pulses are combined in a coincidence amplifier to produce the range notch?

1. The phantastron gate and fixed reference marks
2. The phantastron gate and movable reference marks
3. The A-trigger and fixed reference marks
4. The A-trigger and movable reference marks

10-65. To obtain target range there must be coincidence of the

1. phantastron gate and fixed reference marks
2. phantastron gate and movable reference marks
3. movable range pulse and the target's video pip
4. movable range pulse and movable reference marks

10-66. An automatic tracking system is designed to fulfill which of the following purposes?

1. To locate targets
2. To keep radar on target
3. To activate radar system
4. All of the above

10-67. In an automatic tracking system, what determines the direction of the error signal that is sent to the servosystem?

1. The amplitude of the error signal
2. The strength of the video signal
3. The polarity of the error signal
4. The amount of delay of the video signal

IN ANSWERING QUESTION 10-68, REFER TO FIGURE 9-33 OF THE TEXT. ASSUME THAT THE TARGET IS LOCATED AT 180 DEGREES.

10-68. At what bearing would you receive the least amount of video return?

1. 0°
2. 90°
3. 180°
4. 270°

Assignment 11

Fire Control Radar Maintenance

Text: NAVEDTRA 10207-B; pages 9-36 through 11-13

Learning Objective: Identify the principles of operation of built-in test devices in fire control radars.

11-1. Maintenance of radar equipment requires a system of which of the following procedures?

1. Operations
2. Tests and measurements
3. Moving
4. Installation

11-2. What is the purpose of a directional coupler?

1. To provide a means of sampling the rf energy traveling in one direction of a waveguide
2. To provide a means of sampling the rf energy traveling in either direction of a waveguide
3. To connect the transmitter to the antenna
4. To connect the antenna to the receiver

11-3. Which of the following will affect the degree of coupling between the waveguide and the directional coupler?

1. The number of coupling holes
2. The position of the coupling holes
3. The size of the coupling holes
4. All of the above

IN ANSWERING QUESTION 11-4, REFER TO FIGURE 9-36 OF THE TEXT.

11-4. If the directional coupler were reversed, what would result?

1. Transmitted power would be measured
2. Reflected power would be measured
3. No rf power would be measured
4. Inaccurate measurements would occur

11-5. When compared to a directional coupler using two coupling holes, a directional coupler using three coupling holes has which of the following advantages?

1. Reduced directivity attenuation
2. Increased directivity attenuation
3. Reduced frequency sensitivity
4. Increased frequency sensitivity

11-6. What is the purpose of a bidirectional coupler?

1. To provide a means of sampling the rf energy traveling in one direction of a waveguide only
2. To provide a means of sampling the rf energy traveling in either direction of a waveguide
3. To connect the transmitter to the antenna
4. To connect the antenna to the receiver

11-7. A bolometer is a device constructed of temperature-sensitive material used to perform which of the following functions?

1. Supply rf energy
2. Transmit rf energy
3. Measure rf energy
4. All of the above

11-8. A barretter differs from a thermistor in which of the following ways?

1. It increases its resistance with a rise in temperature
2. It can operate over a wider range of frequencies
3. It has a higher degree of precision
4. It can dissipate more power

IN ANSWERING QUESTION 11-9, REFER TO FIGURE 9-38B OF THE TEXT.

11-9. What is the purpose of thermistors TH2 and TH3 in the bridge circuit?

1. To compensate for power consumption of TH2
2. To compensate for temperature variations of the bolometer mount
3. To control the amount of rf energy applied to TH2
4. To control the temperature of the waveguide

11-10. Which of the following factors causes a bolometer to measure the average power level instead of the peak power level?

1. The size of the bead thermistor
2. The size of the attenuator
3. The type of coupling device
4. The thermal time lag

11-11. A dummy antenna or load serves which of the following purposes?

1. A receiving point for returned rf energy
2. A radiating point for transmitted rf energy
3. A terminating point for transmitted rf energy
4. All of the above

Learning Objective: Explain the principles of operation of the more common radar test sets.

11-12. Which of the following properties of a radar transmitter's output is measured by the portable test set (TS-147)?

1. Frequency
2. Power
3. Both 1 and 2 above
4. Voltage

11-13. An rf signal is generated within the TS-147 by which of the following components?

1. Magnetron
2. Reflex klystron
3. Hartley oscillator
4. Colpitts oscillator

11-14. Indirect reading of rf power as measured by the TS-147, is obtained by which of the following methods?

1. By reading both the meter and the absorption cavity dial
2. By reading the calibrated attenuator dial
3. By reading both the step attenuator and the calibrated attenuator dials
4. By reading the absorption cavity dial

11-15. Radio frequency as measured by the TS-147 is obtained by reading

1. both the meter and the absorption cavity dial
2. the calibrated attenuator dial
3. both the step attenuator and the calibrated attenuator dials
4. the absorption cavity dial only

11-16. What precaution must be taken when you measure power with the TS-147?

1. Tune the power-set attenuator
2. Tune the absorption cavity
3. Detune the absorption cavity
4. Detune the power-set attenuator

11-17. To which portion of a radar receiver's response curve should a radar transmitter's frequency spectrum be positioned to ensure maximum efficiency of the radar?

1. The first portion
2. The center portion
3. The last portion
4. Either 1 or 3 above; depending on accuracy

11-18. What signal components are contained in the spectrum of the output of a pulse modulated rf oscillator?

1. Fundamental frequency
2. Fundamental frequency with modulation sidebands
3. Fundamental frequency plus modulator frequency
4. Fundamental frequency minus modulator frequency

11-19. The received frequency of a spectrum analyzer is swept across the desired range in what manner?

1. By varying the size of the frequency meter cavity
2. By varying the size of the klystron cavity
3. By applying a sawtooth voltage to the crystal mixer
4. By applying a sawtooth voltage to the klystron

IN ANSWERING QUESTION 11-20, REFER TO FIGURE 9-45 OF THE TEXT.

11-20. The illustrated pattern appears on the indicator of the spectrum analyzer when the frequency meter dial reads 9122.5 megahertz. As the frequency meter is detuned slightly, the center amplitude of each spectrum rises. What is the frequency of the unknown signal?

1. 9100.0 MHz
2. 9122.5 MHz
3. 9145.0 MHz
4. 9167.5 MHz

Learning Objective: Identify the functions and operating principles of weapons direction and designation equipment.

11-21. Which of the following systems coordinates all the elements of a fire control problem to ensure maximum probability of a kill?

1. NTDS
2. FCS
3. WDS
4. WCS

11-22. What is the primary source of air target information during the detection operation?

1. NTDS
2. Navigation radar
3. Fire control radar
4. Search radar

11-23. Which of the following methods may be used to identify a target as friendly?

1. Visual identification
2. Verbal communication
3. IFF transmission
4. All of the above

11-24. Which of the following equipment provides the link between the search radar and the fire control system?

1. The WDE
2. The computer system
3. The data transmitter
4. The TSTC

11-25. The assignment of a fire control system to a target is based on which of the following target evaluations?

1. Speed
2. Direction
3. Intent
4. Threat

11-26. A total of how many tracking channels are available on a TSTC?

1. Six
2. Seven
3. Eight
4. Nine

11-27. What is the primary function of the DAC?

1. To track targets
2. To fire weapons
3. To determine engagement sequence
4. To identify targets

11-28. Which of the following quantities is/are displayed on the DAC multi-purpose presentation?

1. Target height
2. Target speed
3. Engagement time factors
4. All of the above

11-29. Designation priority is given to targets tracked by which of the following equipment?

1. Search radar
2. Missile fire control radar
3. Target designation transmitter (TDT)
4. Gun fire control radar

11-30. Target selection and channel assignment with the TSTC is accomplished by which of the following actions?

1. By depressing the rate-aid switch
2. By depressing one of the channel push-buttons
3. By placing the pantograph arm dot on the target video
4. By simultaneous performance of both 2 and 3 above

11-31. Assume that the TSTC operator has detected a target and assigns a tracking channel. How will the tracking channel assignment appear on the radarscope of the TSTC?

1. A letter and a number will be superimposed on the target video
2. A small illuminated dot will be superimposed on the target video
3. A letter within a small illuminated circle will be superimposed on the target video
4. A letter and semicircle within a large circle will be superimposed on the target video

11-32. The TSTC tracking operators in weapons control will commence tracking when

1. a small illuminated circle containing a letter superimposed on the target appears on their radarscopes
2. an illuminated number superimposed on the target appears in the radarscope
3. they receive, by voice communication, the order to do so from the WLO
4. the target symbol appears on their radarscopes

11-33. How is the EWRR inserted into the weapons direction system?

1. Manually by the TSTC operator
2. Manually by the WLO
3. Automatically by the computer
4. Automatically by the director

11-34. How is the target height determined on a TSTC used with a 3-coordinate radar?

1. By automation
2. By aligning a measuring spot with the video display of the target
3. By placing the pantograph arm directly over the video dot
4. By voice communication

11-35. What is a significant advantage afforded by the use of multipurpose presentations on a DAC over a normal PPI presentation?

1. An assignment of targets to directors can be made on a selective basis
2. The weapon's blind zone can be more easily determined
3. A more accurate EWRR is possible
4. The vertical time lines on the console display become unimportant

11-36. Assume that you are the operator of a DAC. What method would you use to assign director 3 to track the target in channel A?

1. Depress simultaneously the director 3 pushbutton in the "designate to" column and the channel A pushbutton in the "designate from" column
2. Depress the director 3 pushbutton in the "designate from" column, release the pushbutton, and then depress the channel A pushbutton in the "designate to" column
3. Depress simultaneously the director 3 pushbutton in the "designate from" column and the channel A pushbutton in the "designate to" column
4. Depress the director 3 pushbutton in the "designate to" column, release the pushbutton, and then depress the channel A pushbutton in the "designate from" column

11-37. What type of input data supports ownship data inputs to NTDS?

1. Aircraft
2. Other ships
3. Shore stations
4. All of the above

11-38. What NTDS data link is used for long-range communications between NTDS units?

1. Link 11
2. Link 14
3. Link 16
4. Link 4A

Learning Objective: Identify the functions of, and the relationship between, the major units of a gunfire control system.

11-39. What factor(s) is/are established by all GFCS?

1. Lead angles
2. The line of sight
3. The line of fire
4. All of the above

11-40. In what section of the fire controls system are lead angles calculated?

1. Stable element
2. Director
3. Computer
4. WDE

11-41. Which of the following fire control problem invariants define the position of the aiming point?

1. Los
2. Lof
3. Lead angle
4. Level angle

11-42. The reference planes used by the fire control system are established by which of the following equipment?

1. Computer
2. Stable element
3. Director
4. WDS

Learning Objective: Explain the relationship between major units of the GFCS Mk 68, and trace data flow through these units.

11-43. Which major unit of the GFCS Mk 68 produces the gun orders for star shell fire of 5" guns?

1. Computer Mk 47
2. Computer Mk 116
3. Computer Mk 1A
4. Gun Order Converter Mk 20

11-44. What does the optical equipment of the Mk 68 director consist of?

1. A stereoscopic rangefinder, the trainer's and pointer's telescopes, and the control officer's slew sight
2. A stereoscopic rangefinder, the tracker's telescope, and the director officer's sighting unit
3. A tracking telescope and the control officer's sighting unit
4. A gunsight

TO ANSWER QUESTIONS 11-45 THROUGH 11-47, SELECT FROM COLUMN B THE UNITS OF THE DIRECTOR ROTATED BY THE POWER DRIVE IN COLUMN A.

	A. POWER DRIVES	B. UNITS AND PLANES
11-45.	Crosslevel	1. Entire director
11-46.	Train	2. Optical equipment and the radar antenna
11-47.	Elevation	3. Director Shield
		4. Optical equipment only

11-48. In what type(s) of control can the power drives of the GFCS Mk 68 be operated?

1. Local and automatic
2. Manual and local
3. Handwheel and normal
4. Only automatic

11-49. Which member of the director crew selects the type of control of the power drives?

1. The director officer
2. The pointer
3. The trainer
4. The tracker

11-50. In which mode of operation do the power drives function as position control servos?

1. The console mode
2. The DO control mode
3. The tracker mode
4. The target designation mode

11-51. Assume that the director is in the target designation mode of operation, and the director officer (DO) presses the right-hand trigger switch on the one-man control unit (OMC). What mode of operation will the director be in after this action?

1. Auto-track
2. Console
3. Director officer control
4. Tracker control

11-52. In the firing circuit, which position of the director officers selector switch opens both the cease firing and firing circuits?

1. Normal
2. Check
3. Cease
4. Open

11-53. On the AN/SPG 53 radar, the trainer's foot switch is used to

1. deenergize the designation circuits
2. deenergize the optical tracking circuits
3. energize the designation circuits
4. energize the automatic tracking circuits

11-54. The radar range operator's foot switch is used to

1. deenergize the range designation circuits
2. deenergize the optical tracking circuits
3. energize the designation circuits
4. energize the automatic tracking circuits

11-55. In automatic control, the Mk 47 computer can compute solutions for which of the following target types?

1. Surface
2. AA sonic
3. AA supersonic
4. Each of the above

11-56. The scale factor change needed to accommodate targets of different speeds in the Mk 47 computer is accomplished by which of the following methods?

1. By shifting the phase relationship
2. By shifting to different circuits
3. By changing the time line speed
4. By changing component values in the relative motion circuits

11-57. When the system is in the optical range mode of operation, how is range rate controlled?

1. Manually
2. Automatically with the time line on slow speed
3. Automatically with the time line on medium speed
4. Automatically with the time line on fast speed

11-58. In what mode of operation does the Mk 47 computer transmit director position to the designation equipment?

1. Designation mode only
2. Optical range mode only
3. Auto-track mode only
4. All modes of operation

11-59. What outputs of the Mk 16 stable element are transmitted electrically?

1. Level to the Mk 47 computer
2. Crosslevel to the Mk 47 computer
3. Crosslevel to the Mk 68
4. All of the above

Learning Objective: Explain the relationship between major units of the GFCS Mk 86.

11-60. The Mk 86 is designed to track a total of how many surface targets simultaneously?

1. One
2. Two
3. Three
4. Four

TO ANSWER QUESTIONS 11-61 THROUGH 11-65, SELECT FROM COLUMN B THE UNIT OF THE MK 86 SYSTEM THAT PERFORMS THE TASK LISTED IN COLUMN A.

	A. TASKS		B. UNITS
11-61.	Functions as a gun director	1.	Signal data translator
11-62.	Provides TV information	2.	Control officer console
11-63.	Converts digital gun orders to analog information	3.	Gun control console
11-64.	Monitors the overall fc system	4.	Optical sighting system
11-65.	Converts analog information to digital signals for computer use		

11-66. The TV camera aligned with the AN/SPG-60 radar antenna has its display and controls located on the/an

1. NTDS console
2. GOC console
3. GCC1 console
4. GCC2 console

11-67. The Mk 86 system has the capability of interrogating, receiving, and decoding beacon responses. This capability is an integral function of what portion of this system?

1. Surface search radar
2. Air search radar
3. Remote optical system
4. Cw illuminator

TO ANSWER QUESTIONS 11-68 THROUGH 11-70, SELECT FROM COLUMN B THE MODE OF OPERATION OF THE MK 86 SYSTEM THAT FULFILLS THE USE IN COLUMN A.

	A. USES		B. MODES
11-68.	Used when shore targets cannot be detected by radar or the optical system	1.	Surface radar
		2.	Surface/shore visual
11-69.	Used for tracking low flying aircraft	3.	Shore indirect
11-70.	Used against an enemy surface ship when radar is the prime information source	4.	Air action/visual

Assignment 12

Overview of Gun Fire Control Systems; Battery Alignment

Textbook Assignment: FTG 3&2, NAVEDTRA 10207-B; pages 11-14 through 12-23

Learning Objective: Identify the characteristics, major components, and operating modes of the Close-in-Weapon System (CIWS) Mk 15.

12-1. Which of the following components of the CIWS is located in the combat information center (CIC)?

1. The ECG
2. The RCP
3. The LCP
4. The VRU

12-2. What component of the CIWS provides the only computer entry point for threat and engagement data?

1. The ECG
2. The RCP
3. The LCP
4. The VRU

QUESTIONS 12-3 AND 12-4 ARE TO BE JUDGED TRUE OR FALSE.

12-3. The controls, indicators, and support equipment associated with the remote control panel (RCP) are used for operability tests and fault isolation.

1. True
2. False

12-4. The search and track radars of the CIWS share the same transmitter and receiver.

1. True
2. False

12-5. What is the maximum track antenna train search angle?

1. 5°
2. 10°
3. 15°
4. 20°

12-6. What type of computer is used in the CIWS?

1. A general-purpose digital
2. A special-purpose digital
3. A general-purpose analog
4. A special-purpose analog

12-7. Waveguide air pressure is provided by which of the following units of the CIWS?

1. The LCP
2. The RCP
3. The ECG
4. The VRU

12-8. The call-up and readout of test points throughout the CIWS is centralized in which of the following units?

1. The WCG
2. The TCU
3. The CSE
4. The PSE

12-9. Expressed in degrees per second, what is the maximum tracking rate in (a) elevation and (b) train?

1. (a) 86° (b) 100°
2. (a) 100° (b) 86°
3. (a) 75° (b) 110°
4. (a) 110° (b) 75°

12-10. What methods are used to (a) control and (b) drive the M61A1 Gatling gun?

1. (a) Mechanical (b) hydraulic
2. (a) Hydraulic (b) mechanical
3. (a) Electrical (b) hydraulic
4. (a) Hydraulic (b) electrical

12-11. Which of the following CIWS modes of operation allow(s) acceptance of remotely designated targets?

1. AAW Manual
2. AAW Auto
3. Air Ready
4. All of the above

12-12. What unit continues to operate when the CIWS is in the BATTERY OFF mode?

1. The LCP
2. The RCP
3. The WCG
4. The ECG

12-13. Warm-up power to the transmitter and spin-up power to the vertical reference unit (VRU) are the only circuits energized in what CIWS mode of operation?

1. STANDBY
2. ELX power
3. AIR READY
4. AAW MANUAL

12-14. Target designation and firing control commands from a TDT are used in what CIWS modes of operation?

1. AAW AUTOMATIC
2. AAW MANUAL
3. SURFACE
4. STANDBY

12-15. What is the normal mode of operation of the CIWS?

1. Automatic search with manual override
2. Manual
3. Surface search with manual override
4. Air ready

12-16. The CIWS determines the angular error between the target and the aiming point by what method?

1. Comparing target's position within the tracking beam to a reference
2. Phase analysis of target returns
3. Tracking the projectiles and comparing projectile position with the target position
4. Angular rate analysis

Learning Objective: Identify the major components and operational principles of the HARPOON weapon system, including the HARPOON missile.

12-17. The HARPOON system is designed to destroy what type of target?

1. A short-range, air
2. A long-range, air
3. An over-the-horizon, surface
4. A short-range, surface

12-18. The HARPOON Ship Command and Launch Control Set (HSCLCS) provides which of the following functions?

1. The application of missile warm-up power
2. The control of launch sequence
3. The supply of target data to the missile
4. All of the above

QUESTION 12-19 IS TO BE JUDGED TRUE OR FALSE.

12-19. The Weapons Control Console (WCC) houses an analog computer that computes missile orders.

1. True
2. False

12-20. Which of the following inputs or controls is entered at the Weapons Control Indicator Panel (WCIP)?

1. Target data
2. Ownship data
3. Missile selection
4. Each of the above

QUESTION 12-21 IS TO BE JUDGED TRUE OR FALSE.

12-21. HARPOON missiles may be launched from both TARTAR and ASROC launchers.

1. True
2. False

12-22. What HARPOON system unit contains the firing interlocks required to fire a series of missiles in ripple sequence?

1. The WCC
2. The LSU
3. The HCL
4. The WCIP

12-23. What type of guidance is used in the HARPOON missile?

1. Passive homing
2. Active
3. Semiactive
4. Beam-rider

12-24. The HARPOON missile is divided into what total number of sections?

1. Five
2. Two
3. Three
4. Four

12-25. What type of engine is used to maintain the HARPOON missile in flight after booster separation?

1. A solid-fuel rocket
2. A liquid-fuel rocket
3. A turbojet
4. A ram jet

12-26. The seeker radar is used during what phase of HARPOON missile guidance?

1. The initial launch phase
2. The boost phase
3. The mid-course phase
4. The terminal phase

12-27. When is the warhead of a HARPOON missile armed?

1. Prior to launch
2. At booster separation
3. During mid-course guidance phase
4. During terminal guidance phase

12-28. Which of the following features of the HARPOON missiles flight profile causes it to be difficult to detect or shoot down?

1. Active homing
2. Low level (just above the water) flight path
3. Extremely high flight path
4. Passive homing

Learning Objective: State the purpose of battery alignment and identify the methods used in battery alignment.

12-29. Which of the following conditions indicates a correctly aligned weapons system?

1. All associated units remain parallel when trained to zero degrees (relative)
2. All associated units remain parallel when trained to 180 degrees (relative)
3. All associated units remain parallel when elevated to zero degrees
4. All associated units remain parallel throughout all operating motions of the units

12-30. Battery alignment is based on which of the following concepts?

1. Parallel lines
2. Parallel planes
3. A geometric coordinate system
4. All of the above

12-31. By what two types of angles are directions specified in the complete reference frame?

1. Train and parallax angles
2. Train and elevation angles
3. Elevation and traverse parallax angles
4. Traverse and lead angles

12-32. What is used as the reference direction in naval combat systems?

1. Line of sight of the reference element
2. Ship centerline, pointing toward the stern
3. Ship centerline, pointing toward the bow
4. Line perpendicular to the centerline

12-33. In naval combat systems, the reference plane is parallel to which of the following planes?

1. Reference element roller path
2. Horizontal
3. Deck
4. Vertical

12-34. Under which of the following circumstances is original alignment performed?

1. When a repair has been accomplished
2. When a weapons system is first installed
3. When a modified system is installed
4. Either 2 or 3 above

12-35. The major distinction between original alignment and alignment afloat is that ship's personnel
perform ____(a)____ alignment
drydock, afloat
and shipyard personnel perform ____(b)____ alignment.
drydock, afloat

1. (a) drydock (b) afloat
2. (a) afloat (b) afloat
3. (a) afloat (b) drydock
4. (a) drydock (b) drydock

12-36. Which of the following sources of error is/are present to some degree in all readings taken during battery alignment?

1. Human error
2. Lost motion
3. Instrument error
4. All of the above

12-37. After initial battery alignment in drydock, a follow-up alignment when the ship is afloat must be accomplished for which of the following reasons?

1. To compensate for changes in mechanical alignment caused by hull flexibility
2. To eliminate future alignments until the next drydock period
3. To correct changes in the electrical transmission system
4. To correct errors made by the yard force

12-38. Roller paths are machined parallel to which of the following planes?

1. Horizontal
2. Deck
3. Vertical
4. Normal

12-39. After a ship is waterborne, the weapons system reference plane (deck plane) is a plane that is parallel to which of the following planes?

1. Reference element bore sight axis at 000° elevation
2. Horizontal, as established by the stable element
3. Reference element roller path
4. Stable element roller path

12-40. What is the purpose of a tram bar?

1. To establish the system reference plane
2. To set an element to an exact position
3. To establish the systems relationship to the center line
4. To correct for the effects of parallax between elements

12-41. How are the zero line and scribe mark of a telescoping tram bar checked for accuracy?

1. By comparison with a rigid tram bar for the same element
2. By tramming the reference element and reading the dials
3. By tramming two elements and comparing the readings
4. By using the tram bar gage

12-42. What safety precaution, both for personnel and equipment, should be strictly observed when tramming an element?

1. Tramming operations should be performed only in port
2. Always tram with the marks or blocks moving
3. All electrical power to the element power drives should be deenergized
4. Always tram with the marks or blocks moving toward each other only

12-43. Bench marks are reference marks used to verify which of the following angular relationships between an element and the ship's structure?

1. Los in train only
2. Los in elevation only
3. Los in train and elevation
4. Lof in train only

12-44. What is used to establish the pointing line of an element?

1. A tram bar
2. An optical alignment sight
3. An electronic alignment sight
4. A bench mark

12-45. The pointing line of a gun mount is established by which of the following methods?

1. Placing a boresight telescope in the gun barrel
2. Using an alignment sight mounted on the director
3. Using tram bar readings
4. Comparing dial readings from various elements

12-46. Which of the following instruments is used to measure the difference in roller path tilt between the reference element and another element in the system?

1. Star gage
2. Boresight telescope
3. Elevation tram bar
4. Gunner's guadrant

12-47. What must be determined in order to express the tilt of a roller path plane?

1. Bearing of the high point only
2. Inclination at the zero train reference line
3. Relative bearing and amount of tilt at the high point
4. Amount of tilt at the high point only

12-48. What is the primary limitation of clinometers?

1. They are inaccurate
2. They measure large angles
3. They measure only small angles
4. They can only be used in drydock

12-49. Which of the following checks must be made prior to commencing a battery alignment afloat?

1. Transmission check
2. Synchro alignment check
3. Parallax transmission check
4. All of the above

12-50. Benchmarks provide a means for checking which of the following parameters?

1. Director zero train at sea
2. Turret zero train at sea
3. Director center of rotation at sea
4. Mean plane at sea

12-51. When afloat, one of the first steps in aligning a gun battery involves which of the following checks using the reference element?

1. Establishment of the roller-path correction
2. Construction of a radial diagram
3. Establishment of elevation tram marks for the guns
4. Verification of zero train

12-52. What, if anything, is the allowable difference in the readings on the train dial and original recorded value when a benchmark or tram, is used to align a director afloat?

1. Within ±5 minutes of arc of the original recorded value
2. Greater than ±5 minutes of arc of the original recorded value
3. Within ±3 minutes of arc of the original
4. Nothing; the readings must be the same

12-53. Which of the following is a difference between the "Target at Known Range" and the "Target at Infinity" method of battery alignment afloat?

1. Parallax correction is set to zero
2. Parallax correction is set to the value computed for the target at the known range
3. The elevation angle must be zero degrees
4. The elevation angle must be 90 degrees

12-54. Except in extreme emergencies, which of the following targets should NOT be used for train alignment?

1. Star
2. Moon
3. Sun
4. Planet

12-55. For train alignment (Target at Infinity method), the target you select must be 30 degrees or less above the horizon in order to

1. read the dials
2. keep the sights parallel
3. keep the sights on target
4. locate the target

12-56. The primary stations that must be manned for train alignment are the

1. gun and director
2. director and plotting room
3. plotting room and gun
4. transit and gun

IN ANSWERING QUESTIONS 12-57 AND 12-58, REFER TO TABLE 12-1 OF THE TEXT.

12-57. What is the mean lost motion?

1. One minute
2. Two minutes
3. Three minutes
4. Four minutes

12-58. What is the mean gun train indicator error?

1. 1.33 minutes
2. 1.33 degrees
3. 2.66 minutes
4. 2.66 degrees

12-59. When the gun train error is greater than lost motion by more than 2 or 3 minutes, what must be adjusted?

1. Director train output
2. Parallax correction
3. Director train response
4. Gun train response

12-60. In elevation alignment afloat, it is necessary to make the elevation dial of each gun or director read the elevation of that element relative to

1. a plane parallel to the reference plane
2. the mean roller path of the battery
3. the roller path of the element whose roller path is closest to the mean
4. the horizon

12-61. How is the reference element checked to be sure that it is parallel to the drydock zero elevation alignment?

1. By tracking a target
2. By checking with a transmit
3. By comparison to a benchmark
4. By taking tram bar readings

12-62. Elevation alignment data is compiled by which of the following processes?

1. Elevation check
2. Horizon check
3. Gunner's quadrant roller path check
4. Both 2 and 3 above

12-63. The angle through which an element must be depressed below the horizontal in order to sight the horizon is called what?

1. Parallax angle
2. Dip angle
3. Elevation offset angle
4. Horizon angle

12-64. How is the dial misalignment error determined at the end of a horizon check?

1. The dip angle of all elements is subtracted from the dip angle of the reference element
2. The dip error is subtracted from the total constant error
3. The dip error is added to the dip angle of each element
4. The dip angle is added to the parallax angle

12-65. What total number of methods are available for separating the varying factors from the constant factors in the determination of the roller path misalignment between a gun and a director?

1. One
2. Two
3. Three
4. Four

IN ANSWERING QUESTION 12-66, REFER TO FIGURE 12-20 OF THE TEXT.

12-66. What is (a) the bearing of the high point and (b) the constant system error?

1. (a) 10° (b) 10'
2. (a) 20° (b) 17'
3. (a) 30° (b) 22'
4. (a) 40° (b) 25'

12-67. Because forming a curve is sometimes difficult in the rectangular coordinate method, the method sometimes preferred is called the

1. circular method
2. relative bearing method
3. polar coordinate method
4. universal method

12-68. Which of the following corrections is/are eliminated by using the polar coordinate method?

1. System error
2. Dip difference
3. Sight angle
4. Both 2 and 3 above

12-69. What is the disadvantage of the polar coordinate method of horizon check data analysis?

1. Vertical parallax is not shown
2. System error is not shown
3. Element bearing is not shown
4. Target position is not shown

IN ANSWERING QUESTIONS 12-70 THROUGH 12-72, REFER TO FIGURE 12-21 OF THE TEXT.

TO ANSWER QUESTIONS 12-70 THROUGH 12-72, SELECT FROM COLUMN B THE CORRECT COLUMNS THAT THE INFORMATION IN COLUMN A IS ENTERED UNDER.

	A. INFORMATION	B. COLUMNS
12-70.	Train angle	1. Col 1
12-71.	Train angle +60°	2. Col 2
		3. Col 3
12-72.	Uncorrected gun error	4. Col 4

Assignment 13

Spotting and Naval Gunfire Support

Textbook Assignment: FTG 3&2, NAVEDTRA 10207-B; pages 13-1 through 13-15

Learning Objective: Define spotting and the various terms used in relation to spotting.

13-1. Estimating the corrections needed in range, elevation, and deflection to hit a target is called

1. observing corrections
2. correcting errors
3. spotting fall of shot
4. establishing errors

13-2. Spotting procedures are normally NOT applied to which of the following types of targets?

1. Air
2. Surface
3. Elevated land
4. Obscured land

13-3. What term is used to define the firing of one gun or the simultaneous firing of two or more guns of a battery at the same target?

1. Slow fire
2. Salvo fire
3. Rapid fire
4. Slow salvo fire

13-4. The hitting space is measured in which of the following dimensions?

1. Range
2. Bearing
3. Height
4. All of the above

13-5. A spotter shouldn't be too quick to correct a series of satisfactory salvos if one or two seem to wander because

1. no change has taken place
2. the mean point of impact will differ slightly for every salvo
3. personnel errors may have an effect
4. the target is moving

Learning Objective: List the qualifications and duties that are required for a spotter.

13-6. Which of the following qualifications is/are required for a spotter to be classified as good?

1. Be calm under stress
2. Have sound judgement
3. Have normal hearing
4. All of the above

13-7. What is the primary function of a spotter?

1. To describe enemy forces
2. To inform control of the tactical situation
3. To correct fall of shot to the target
4. To act as the control officer

13-8. Which of the following is a deflection unit of measure?

1. Degree
2. Radian
3. Mil
4. Minute

Learning Objective: Identify the methods used in spotting.

13-9. Which of the following is a feature of a spotting diagram?

1. The horizontal lines represent equal distances
2. The horizontal lines are spaced equally
3. The curves represent a two-dimensional situation
4. Each spotting diagram can be used at several different observer heights

13-10. What is the preferred method of spotting fall of shot?

1. Direct
2. Bracket
3. Halving
4. Ladder

13-11. What factor limits the accuracy of determining corrections by the direct spotting method?

1. Target speed
2. Target range
3. Target size
4. Ownship's speed

13-12. Which, if any, of the following may be used as an aid for the spotter in short range spotting situations?

1. Target silhouette
2. Target characteristics
3. Short range spotting diagrams
4. None of the above

13-13. What is the method of spotting in which fire is opened so that the fall of shot will be short of the target?

1. Direct
2. Bracket
3. Halving
4. Ladder

13-14. What procedure may be used after a target has been straddled using the ladder method of spotting?

1. Bracket and halving
2. Rocking ladder
3. Ladder
4. Direct

13-15. Pyramiding of spots will usually occur only when the gun battery is firing

1. slow salvo fire
2. slow fire
3. rapid fire
4. harassment fire

13-16. The time-of-flight signal mechanism serves to

1. average out the MPI error
2. decrease the size of certain types of accidental errors
3. inform the control officer when to fire another salvo
4. help the spotter avoid spot pyramiding

13-17. The time-of-flight signal indicates the time of flight by what method?

1. A buzzer sounding just before the salvo lands
2. A light flashing just before the salvo lands
3. A dial approaching zero as the salvo approaches the target
4. A dial indicating the time of flight in seconds

Learning Objective: Identify the various classifications and methods of fire employed in naval gunfire support.

TO ANSWER QUESTIONS 13-18 THROUGH 13-20, SELECT FROM COLUMN B THE CLASS OF FIRE USED TO PERFORM THE TASK IN COLUMN A.

	A. TASKS	B. CLASSES
13-18.	To prevent the use of a tank	1. Destructive fire
		2. Interdiction fire
13-19.	To destroy a tank	
		3. Neutralization fire
13-20.	To eliminate the use of a runway	
		4. Preparation fire

13-21. When you have a target whose axis is not parallel to the lof, and friendly forces are NOT within 600 yards, the classification of fire is called

1. harassing fire
2. illumination fire
3. deep supporting fire
4. close supporting fire

FOR QUESTIONS 13-22 THROUGH 13-26, ASSUME THAT YOUR SHIP IS ASSIGNED A FIRE SUPPORT STATION FOR A LANDING BY FRIENDLY TROOPS ON AN ENEMY HELD BEACH.

13-22. The first type of fire that is delivered just prior to the actual landing of the troops should be

1. preparation fire
2. harassing fire
3. interdiction fire
4. close supporting fire

13-23. Prior to the landing, it was determined that at landing time (H-hour) + 1 hour your ship would deliver fire at area X-ray. This type of fire is called

1. call fire
2. destruction fire
3. scheduled fire
4. reconnaissance fire

13-24. The troops ashore request a fire mission. This is called

1. neutralization fire
2. interdiction fire
3. deep supporting fire
4. call fire

13-25. During the call fire mission, enemy artillery starts firing at your ship. The ship returns the fire by the use of

1. counterbattery fire
2. opportunity fire
3. reconnaissance fire
4. destruction fire

13-26. It is believed that enemy troops are massed in a densely wooded area. To determine this, your ship employs

1. opportunity fire
2. reconnaissance fire
3. deep supporting fire
4. close supporting fire

TO ANSWER QUESTIONS 13-27 THROUGH 13-29, SELECT FROM COLUMN B THE TYPE OF FIRE USED FOR THE TARGETS IN COLUMN A.

	A. TARGETS	B. TYPES OF FIRE
13-27.	Behind a hill	1. Area
13-28.	A prescribed map section	2. Enfilade
		3. Point
12-29.	A particular target	4. Defilade

Learning Objective: Identify the terms used in Naval Gunfire Support (NGFS).

TO ANSWER QUESTIONS 13-30 THROUGH 13-32, SELECT FROM COLUMN B THE TERM USED TO COMMUNICATE THE DESIRED INFORMATION IN COLUMN A.

	A. INFORMATION	B. TERMS
13-30.	The round is to land in 5 seconds	1. Lost
		2. Delay
13-31.	The round was not observed	3. Standby
13-32.	The last transmission was incorrect	4. Wrong

13-33. The target you are firing at has been destroyed. Instead of receiving "End of Target," you receive a spot of "Right 500, Add 200, No Change." The term used to define this change is called

1. check fire
2. fresh target
3. record as target
4. no fire lines

13-34. Which of the following information must be retained when the term "Record as Target" is received?

1. Present solution
2. Range spot
3. Deflection spot
4. All of the above

13-35. The ship has relayed the location of the impact point of the first salvo of a mission to the spotter. Which of the following terms describe(s) the situation where this information is required?

1. Record as target
2. Danger close
3. No fire lines
4. All of the above

TO ANSWER QUESTIONS 13-36 THROUGH 13-38, SELECT FROM COLUMN B THE TYPE OF FUZE USED TO CREATE THE EFFECT IN COLUMN A.

	A. EFFECTS	B. FUZES
13-36.	Impact detonation	1. Time
13-37.	Projectile penetration	2. Quick
		3. VT
13-38.	Air burst	4. Delay

Learning Objective: Identify the various methods of fire and how each is employed.

TO ANSWER QUESTIONS 13-39 THROUGH 13-41, ASSUME THAT YOUR SHIP IS ON AN INDIRECT FIRE MISSION, USING CIC. CIC'S PLOT OF YOUR SHIP'S COURSE INCLUDES:

PROJECTED PLOTS	PROJECTED EVENTS
A	POSITION DETERMINED
B	COURSE AND SPEED DETERMINED
C	WORK "MARK" PASSED
D	MARKING EVERY 15 SECONDS
E	COMPUTER RANGE AND BEARING AGREES WITH PLOTTED RANGE AND BEARING

13-39. How, and from where, does the computer receive range and bearing?

1. Manually, CIC
2. Automatically, CIC
3. Manually, director
4. Automatically, director

13-40. At what point on a track is the time motor of the computer turned on?

1. A
2. B
3. C
4. D

13-41. At what point on the track is it safe for plot to pass the word "READY" to the shore fire control party?

1. B
2. C
3. D
4. E

13-42. In the point OSCAR method of fire, the solution to the fire control problem is generated around

1. a point established by the director's line of sight
2. a point plotted by CIC
3. your ship's position
4. the target position

13-43. What method is used to update spots in point OSCAR fire?

1. Use spots from the shore spotter
2. Use spots from the initial GTL
3. Use a transparent overlay with 100 yd squares
4. Use spots from an air spotter

13-44. When visibility is limited, what method of gunfire support may be used most effectively?

1. Director control
2. Reverse slope
3. Point OSCAR
4. Radar beacon

13-45. Reverse slope fire is another name for what type of naval gunfire?

1. Direct fire
2. Radar beacon fire
3. Defilade fire
4. Point OSCAR fire

13-46. When an angle of fall must be chosen that is greater than the angle of the reverse slope, which of the following solutions may be used?

1. Reduce the range
2. Reduce the angle of departure
3. Use a reduced-velocity charge
4. Use an increased-velocity charge

13-47. When the ship fires over friendly troops on an elevated position between the ship and the target, what elevation figures must be determined?

1. Target elevation
2. Troop position elevation
3. The difference between 1 and 2
4. All of the above

13-48. The target grid system was developed for use by

1. air spotters
2. shore spotters
3. shipboard spotters
4. air spotters in conjunction with shipboard spotters

13-49. The target grid system permits the spotter to make observations and corrections with respect to what reference?

1. Line of fire
2. Line of sight
3. Gun-target line
4. Observer-target line

13-50. On board your ship the observations and corrections of the spotter are converted to what reference?

1. GTL
2. OTL
3. lof
4. los

Assignment 14

Underwater Fire Control

Textbook Assignment: FTG 3 & 2, NAVEDTRA 10207-B; pages 14-1 through 15-23

Learning Objective: Identify the methods of target detection in the underwater fire control problem.

14-1. What disadvantage to the submarine's mission results from using the periscope or radar rather than sonar?

1. Limited ability to detect targets
2. Limited submerged depth
3. Reduced concealment
4. Both 2 and 3 above

14-2. By using the periscope, which of the following improvements is gained in target detection?

1. Accurate measurement of range and bearing to the target
2. Positive identification of the target
3. Classification as friend or foe without challenging
4. Each of the above

14-3. What sonar basically functions the same as a pulse radar?

1. An active
2. A passive
3. An echo ranging
4. Each of the above

14-4. Why does sound travel faster through water than through air?

1. Because air is denser than water
2. Because water offers less resistance to sound waves than air
3. Because the particles in water are closer together than the particles in air
4. Because the particles in water are farther apart than the particles in air

14-5. What is the most important factor affecting the speed of sound in water?

1. Temperature
2. Pressure
3. Salinity
4. Chemical composition

14-6. The speed of sound in water will increase if which of the following characteristics of water is increased?

1. Salinity
2. Depth
3. Temperature
4. Each of the above

14-7. What is the most important factor affecting refraction of a sound beam in water?

1. Temperature
2. Pressure
3. Salinity
4. Chemical composition

14-8. Reflection of sound energy occurs anytime the sound medium changes in what way?

1. Thickness
2. Shape
3. Density
4. Temperature

14-9. In which of the following situations will the sound wave transmitted by a submarine and the signal reflected from a target have the same frequency?

1. The submarine and the target are traveling in the same direction at different speeds
2. The submarine and the target are traveling in the same direction at the same speed
3. The submarine and the target are traveling in opposite directions at the same speed
4. The submarine and the target are traveling in opposite directions at different speeds

14-10. What ship noise is easiest to detect with passive sonar?

1. Machinery noise
2. Propeller noise
3. Radio noise
4. Flow noise

14-11. Which of the following components is normally the systems reference point on board a submarine?

1. The periscope
2. A hydrophone
3. The transducer
4. A torpedo tube

14-12. What corrections must be made to the sonar measured target position?

1. Parallax
2. Target travel during sound transit time
3. Refraction of the sound wave
4. All of the above

14-13. To what point on the target is sonar bearing normally measured by a passive sonar?

1. Bow
2. Midships
3. Stern
4. Main mast

IN ANSWERING QUESTIONS 14-14 AND 14-15, REFER TO FIGURE 14-6 OF THE TEXT.

14-14. The distance, L1, that the target moves during transit time of the sound from target to ownship is found by multiplying this transit time by what quantity?

1. Ownship speed
2. Target speed
3. Range to target
4. Target bearing

14-15. The quantity, P2, is the distance between what points on the target?

1. The source of the sound and the stern of the target, when sound is received
2. The source of the sound and the middle of the target, when sound is received
3. The stern and the middle of the target
4. The bow and the middle of the target

14-16. When bearing is measured by a passive sonar, finding the bearing correction angle requires what quantity in the formula?

1. DMt
2. P2
3. R
4. SS

14-17. For which target detecting device must range be computed?

1. Passive sonar
2. Active sonar
3. Periscope
4. Radar

14-18. What quantities of the fire control problem is/are measured by the passive sonar operator?

1. Bearing increments
2. Target course
3. Target speed
4. Range

14-19. Which two quantities are computed by the fire control computer when target position is furnished by the passive sonar?

1. Range and target course
2. Target course and bearing increments
3. Target speed and bearing increments
4. Bearing increments and range

14-20. Which two quantities are computed by the fire control computer when target position is furnished by the active sonar, the radar, or the periscope?

1. Range and target course
2. Target course and speed
3. Target speed and bearing increments
4. Bearing increments and range

14-21. The continuous solution of the relative motion problem is provided by what section of the fire control system?

1. The position keeper
2. The angle solver
3. The detector
4. The analyzer

14-22. Which of the following quantities are normally continuous inputs to the position keeper?

1. Range and relative bearing
2. Target course and speed
3. Ownship course and speed
4. All of the above

14-23. Which of the following inputs are received by the angle solver?

1. Present target position and motion
2. Ownship speed, depth, and course
3. Rate of change of ownship course and torpedo ballistics
4. All of the above

14-24. Ownship data to the angle solver is received from which of the following sources?

1. The gyro compass
2. The dead reckoning analyzer/indicator
3. The depth detector
4. All of the above

14-25. Which of the following ballistic factors require(s) corrections in the straight-run torpedo problem?

1. Tactical speed, Uu
2. Running depth, Hvm
3. Proofing latitude, Ly
4. All of the above

14-26. Corrections to the running speed of the straight-run torpedo are made to compensate for changes in which of the following factors?

1. The tactical speed of the torpedo, jte(Uu)
2. The running depth of the torpedo, jv(Hm)
3. The emergence speed of the torpedo, jm(Hm)
4. All of the above

14-27. The gyro directional correction, j(Cm), compensates for differences between what two ballistic quantities?

1. Proofing depth and running depth
2. Proofing latitude, Ly, and firing latitude, Ly2
3. Enabling run, c(Hm), and torpedo run, Hm6
4. Turning radius, Ym, and gyro angle, G

14-28. Which of the following describes the correction for (a) a linear spread firing pattern and (b) an angular spread firing pattern?

1. (a) Along target track (b) across torpedo track
2. (a) Across target track (b) along target track
3. Both (a) and (b), along target track
4. Both (a) and (b), across target track

IN ANSWERING QUESTIONS 14-29 THROUGH 14-31, REFER TO FIGURE 14-10 OF THE TEXT.

14-29. What quantities are produced by the torpedo prediction problem?

1. Gyro angle, G
2. Torpedo run, Hm6
3. Time of run, T2-6
4. All of the above

14-30. What quantities of the torpedo prediction problem are constant for each type torpedo?

1. Time of run, T2-6, and torpedo run, Hm6
2. Turning radius, Ym, and reach distance, R3
3. Reach distance, R3, and solution angle, B8
4. Gyro angle, G, and turning radius, Ym

14-31. What angle is developed by the turning radius, Ym, of the arc inscribed by the start and completion of the torpedo's turn?

1. Relative target bearing, B
2. Solution angle, B8
3. Target angle, Bts
4. Gyro angle, G

TO ANSWER QUESTIONS 14-32 THROUGH 14-35, SELECT FROM COLUMN B THE QUANTITY THAT IS MODIFIED BY THE BALLISTIC CORRECTION IN COLUMN A.

A. CORRECTIONS	B. QUANTITIES
14-32. Shift along the target track, g(Hm)	1. Gyro angle, G
14-33. Depth change run difference, jv(Hm)	2. Torpedo run, Hm6
14-34. Latitude correction, J(Cm)	3. Time of run, T2-6
14-35. Emergence speed factor, jm(Hm)	4. Target lead distance (target run, H6-5)

14-36. What quantity is added to the straight-run torpedo problem when firing preset programmed torpedoes?

1. Enabling run offset, c(Hm)j
2. Latitude correction, j(Cmo)
3. Torpedo speed correction, jte(Um)
4. Depth change run difference, jv(Hm)

14-37. What method is employed to reduce the possibility of a homing torpedo sinking ownship?

1. The torpedo is fired at a heading opposite to the heading of ownship
2. The torpedo speed is set to a value less than the speed of ownship
3. The torpedo is ordered to maneuver above or below a specific known depth
4. The gyro in the torpedo is provided a large angular adjustment

14-38. What components of the torpedo and target tracks are compared to maintain the wire-guided torpedo on target in bearing rider mode of operation?

1. Ranges
2. Speeds
3. Bearings
4. Positions

14-39. What components of the torpedo and target tracks are compared to maintain the wire-guided torpedo on target in the corrected intercept mode of operation?

1. Ranges
2. Speeds
3. Bearings
4. Positions

Learning Objective: Identify the major sections and operational principles of underwater fire control systems.

14-40. What total number of data sources are used by the data acquisition section?

1. Six
2. Seven
3. Eight
4. Nine

14-41. The ship's inertial navigation system (SINS) provides the FCS continuously with which of the following quantities?

1. North, east, and vertical velocities
2. Latitude and longitude positions
3. Pitch, roll, and heading angles
4. All of the above

TO ANSWER QUESTIONS 14-42 THROUGH 14-44, SELECT FROM COLUMN B THE OUTPUT THAT IS PRODUCED BY THE OWNSHIP SENSOR IN COLUMN A.

	A. SENSORS	B. OUTPUTS
14-42.	Gyrocompass	1. Depth
14-43.	Electromagnetic log	2. Speed
		3. Course
14-44.	Dead reckoning analyzer	4. Position

14-45. Coordinate transformation circuits perform which of the following functions?

1. They convert true bearing to relative bearing
2. They convert relative bearing to true bearing
3. They convert ownship data to a common reference point
4. Both 2 and 3 above

14-46. What section of the underwater fire control system analyzes target motion?

1. The target data selection
2. The data analysis
3. The target position keeping
4. The ownship data selection

14-47. What section of the underwater fire control system determines the future position of the target?

1. The weapon order
2. The data analysis
3. The target data selection
4. The ownship data selection

QUESTION 14-48 IS TO BE JUDGED TRUE OR FALSE.

14-48. When target position keeping data and target motion analysis data disagree, the position keeping data is updated by the motion analysis data.

1. True
2. False

14-49. When a weapon is selected, weapon path computation circuits use which of the following quantities to generate path commands?

1. Ballistic constants
2. Ownship data
3. Target position
4. All of the above

QUESTION 14-50 IS TO BE JUDGED TRUE OR FALE.

14-50. When a wire-guided torpedo is fired, the initial path commands are changed to compensate for changes in target position.

1. True
2. False

14-51. What type of missile is the SUBROC?

1. A guided rocket
2. A guided ballistic missile
3. An unguided rocket
4. An unguided ballistic missile

Learning Objective: Identify the functions and relationships of the major units of the Mk 113 Fire Control System.

14-52. Current target position and weapon orders are computed by the

1. Attack director
2. Stabilization control unit
3. Analyzer console
4. Attack console

14-53. What section of the attack director contains the circuitry to select the source of target range and bearing data?

1. The display section
2. The control section
3. The angle solver section
4. The ballistic computer section

14-54. What section of the attack director indicates that a torpedo has been ordered beyond its operational parameters?

1. Angle solver
2. Ballistic computer
3. Position keeper control
4. Position keeper display

14-55. The signal data converter performs which of the following conversions?

1. Digital-to-digital
2. Digital-to-analog
3. Analog-to-digital
4. Both 2 and 3 above

14-56. The torpedo control console is used with what type(s) of torpedo(es)?

1. Preset straight running
2. Wire-guided
3. Preset programmed
4. All of the above

14-57. Which of the following quantities are NOT set into the torpedo by the torpedo control console during preset operations?

1. Trajectory mode
2. Pre-enable speed
3. Gyro angle
4. Pitch angle

14-58. What total number of torpedoes can be simultaneously programmed and controlled by the torpedo control console?

1. One
2. Two
3. Three
4. Four

14-59. Immediate weapon launching occurs when the weapon monitor panel firing order switch is placed in which of the following positions?

1. SILENT
2. WEAPON LOADED
3. NORMAL
4. WEAPON SELECTED

Learning Objective: Identify the function and relationship of the major units of the Mk 117 Fire Control System.

14-60. The UFCS Mk 117 is capable of controlling which of the following weapons?

1. SUBROC missiles
2. Torpedoes
3. HARPOON missiles
4. All of the above

14-61. What total number of fixed-function pushbuttons are on the weapon control console?

1. 1
2. 8
3. 15
4. 21

14-62. Which controls on the weapon control console allow the operator to edit the displays?

1. The fixed-function switches
2. The numeric entry switches and indicators
3. The variable-function pushbuttons
4. The shaft encoders

14-63. What weapon control console mode of operation allows the operator to determine target course, speed, and range by manipulation of pseudo-(trial) target bearings?

1. Target Motion Analysis mode
2. Control label mode
3. Manual Adaptive TMA Evaluator mode (MATE)
4. Attack Analysis mode

14-64. What unit of the Mk 117 UFCS contains the firing key?

1. The weapon control console
2. The control panel
3. The attack analysis panel
4. The attack control console

14-65. The capability of independently setting a port and starboard torpedo to the same orders is present at what unit of the Mk 117 UFCS?

1. The weapon control console
2. The control panel
3. The attack analysis panel
4. The attack control console

14-66. The weapon data coverter interfaces with which of the following units?

1. The attack center switchboard
2. The torpedo room switchboard
3. The weapons launch console
4. All of the above

14-67. What unit of the Mk 117 UFCS is the power distribution center?

1. The attack center switchboard
2. The torpedo room switchboard
3. The signal data converter
4. The weapon monitor panel

14-68. What total number of memory units are used by the computer set associated with the Mk 117 UFCS?

1. One
2. Two
3. Three
4. Four

14-69. What method of program storage is used by the recorder reproducer?

1. Paper tape
2. Magnetic tape
3. Magnetic disks
4. Core memory units

14-70. The leveling computer performs which of the following functions?

1. Event-to-digital conversion
2. Underwater fire control problem computation
3. Sets initial conditions in SUBROC inertial guidance system
4. Links the system sensors, computational elements, and weapons

14-71. What unit of the Mk 117 UFCS controls the application of power to the weapon?

1. Attack control console
2. Weapon monitor panel
3. Control panel
4. Missile heater controller

Assignment 15

General Maintenance

Textbook Assignment: FTG 3 & 2, NAVEDTRA 10207-B; pages 16-1 through 16-27

Learning Objective: Define the terms preventive maintenance and corrective maintenance, and state the procedures for cleaning and lubricating weapons equipment in accordance with instructions.

15-1. Which of the following actions comes under the heading of preventive maintenance?

1. Replacing the IF strip in a radar receiver
2. Locating a faulty tube in an amplifier
3. Lubricating an antenna drive gear
4. Aligning a newly installed gunsight

15-2. Which of the following solvents is recommended for removing grease from mechanical parts?

1. Soapy water
2. A chlorine solution
3. Benzine
4. Alcohol

15-3. Which of the following actions comes under the heading of corrective maintenance?

1. Retuning a radar receiver after a tube casualty
2. Inspecting a radio transmitter for a loose connection
3. Oiling the gimbal mechanism of a stable vertical
4. Removing dust from the brushes of a generator

15-4. Lenses are usually cemented together with balsam. For this reason, extreme caution should be exercised when cleaning optical equipment with

1. lens paper
2. silica gel
3. methyl chloroform
4. alcohol or ether

15-5. You are directed by your leading FT to conduct an inspection of some optical equipment. What conditions should you look for?

1. Dust and dirt on the lenses
2. Silver plating peeling from mirrors
3. Moisture fogging
4. All of the above

Learning Objective: Identify the procedures for inspecting rotating machinery, cleaning commutators and slipring assemblies, and replacing brushes.

15-6. What is the first step to be undertaken in both preventive and corrective maintenance of electrical equipment?

1. Resistance check
2. Visual inspection
3. Ground check
4. Check for shorts

15-7. When making periodic checks of rotating machinery such as motors, the technician usually must remove the

1. end cover only
2. end cover and brushes
3. sliprings only
4. sliprings and armature

15-8. What should be used to clean the components of rotating machinery such as the commutators and sliprings?

1. Compressed air and a soft brush
2. Crocus cloth and a lint-free rag
3. Solvent (PS-661) and a lint-free cloth
4. Solvent and a soft brush

15-9. Both sliprings and commutators are used to transfer power to and from a moving rotor. The big difference is in their construction. What is the construction of (a) the slipring and (b) the commutator?

1. (a) Solid metal ring
   (b) series of copper segments separated by insulators
2. (a) Series of copper segments separated by insulators
   (b) solid metal ring
3. (a) Split copper ring
   (b) series of metal segments
4. (a) Series of metal segments
   (b) split copper ring

15-10. What should be done to the brushes that are to be reused after a periodic inspection?

1. Clean them with solvent
2. Sand them with emery cloth
3. Replace them in the same holders in the identical position that they formerly occupied
4. Rotate them to different holders, but replace in the same position that they formerly occupied

15-11. When new brushes are sanded-in prior to use, a good way to secure the sandpaper to the commutator is with

1. lacing
2. friction tape
3. rubber bands
4. scotch tape

Learning Objective: Identify a good solder joint and proper techniques for the use of crimp-on terminals, safety wiring, lacing, and bonding.

15-12. What is the appearance of a good solder joint at an electrical connection?

1. Dull
2. Irregular
3. Round and dull
4. Shiny, smooth, and round

15-13. What tool can be conveniently used as a thermal shunt to prevent overheating of small resistors during soldering?

1. Needle-nose pliers
2. Wrench
3. Vise-grip pliers
4. Burnisher

15-14. Crimp-on terminals have which of the following advantages?

1. Little operator skill is required
2. Installation is rapid and uniform
3. Only one tool is required
4. All of the above

15-15. Safety wiring is a method of protection against the effects of what common shipboard condition?

1. Shorts
2. Grounds
3. Arcing
4. Vibration

15-16. What size safety wire is recommended for wiring electrical connectors?

1. 0.032-inch-diameter
2. 0.045-inch-diameter
3. 0.0032-inch-diameter
4. 0.0045-inch-diameter

15-17. What is the advantage of short-section lacing over continuous-cable lacing?

1. It remains tied even though the lacing becomes broken at one point
2. It requires less time to complete
3. It requires ordinary cord
4. It provides better support for the wiring harness

TO ANSWER QUESTIONS 15-18 THROUGH 15-20, SELECT FROM COLUMN B THE DEVICE WHICH SERVES THE PURPOSE DESCRIBED IN COLUMN A.

A. PURPOSES	B. DEVICES
15-18. To prevent high frequency interference	1. Filters
	2. Bonding straps
15-19. To block or bypass undesirable electrical line variations	3. Safety wires
	4. Shielding
15-20. To electrically connect equipment or systems to the ship's structure	

Learning Objective: Identify the correct procedures for troubleshooting and performing module repair, using printed circuit soldering techniques on fire control instruments.

15-21. What is the primary purpose of the adjustments provided in electronic equipment?

1. To permit easy disassembly of the equipment
2. To provide convenient test points
3. To compensate for normal changes in component values
4. To compensate for faulty components in the circuits

15-22. What should be checked after you have located a defective part in an electronic circuit?

1. The circuit wiring for possible wiring changes
2. The fuse in the power supply circuit
3. The ground connection for that piece of equipment
4. The other components in the circuit to determine if any other parts are defective

15-23. What type of soldering iron is recommended for use on printed circuits and electronic modules?

1. A large, high wattage soldering iron
2. A small, low wattage soldering iron
3. A large, high voltage soldering iron
4. A small, low voltage soldering iron

15-24. When soldering components of a printed circuit or electronic module, place the flat side of the tip of the soldering iron directly against the parts to be soldered. (a) Where and (b) when should the solder be applied?

1. (a) To the soldering iron tip
   (b) at the same time the iron is applied to the parts
2. (a) To the soldering iron tip
   (b) 5 to 10 seconds after the iron is applied to the parts
3. (a) To the point of soldering iron contact
   (b) at the same time the iron is applied to the parts
4. (a) To the point of soldering iron contact
   (b) 5 to 10 seconds after the iron is applied to the parts

TO ANSWER QUESTIONS 15-25 THROUGH 15-27, SELECT FROM COLUMN (B) THE DESOLDERING TOOL THAT PERFORMS THE TASK DESCRIBED IN COLUMN (A).

A. TASKS	B. TOOLS
15-25. Fast removal of straight-line multiterminal parts	1. Unger offset tiplet
	2. Bar-type tiplet
15-26. Straightens terminals and leads while melting solder	3. Hollow-cube tiplet
	4. Pyramid tip
15-27. Withdraws solder from circular mounted parts in one operation	

15-28. By what devices are transistors and other components mounted to circuit boards?

1. Bolts
2. Clamps
3. Sockets
4. All of the above

Learning Objective: Identify the troubleshooting aids designed for maintenance of fire control equipment.

TO ANSWER QUESTIONS 15-29 THROUGH 15-31, SELECT FROM COLUMN (B) THE FUNCTION OF THE TROUBLESHOOTING AIDS LISTED IN COLUMN (A).

A. AIDS	B. FUNCTIONS
15-29. One-function schematic diagram	1. To enable determination of the desired ON-OFF stages of control devices
15-30. Data functional diagram	2. To show interconnecting circuits
15-31. Control functional diagram	3. To show circuits relevant to weapon system loops
	4. To determine the troubleshooting aids for the faults observed in the system tests

15-32. What troubleshooting aid may be used to determine the relationships between circuits and components?

1. Voltage distribution diagram
2. Service block diagram
3. Voltage chart
4. One-function schematic

IN ANSWERING QUESTION 15-33, USE THE FOLLOWING INFORMATION:

THE NORMAL PROCEDURE FOR TROUBLESHOOTING IS TO ISOLATE THE TROUBLE, USING THE FOLLOWING STEPS:

A. TO THE UNIT WITHIN THE SYSTEM
B. TO THE STAGE(S) WITHIN THE UNIT
C. TO THE CIRCUIT(S) WITHIN THE STAGE(S)
D. TO THE COMPONENT(S) WITHIN THE CIRCUIT(S)

15-33. For which step are voltage and resistance charts used as a troubleshooting aid?

1. A
2. B
3. C
4. D

Learning Objective: Observe prescribed safety precautions in the handling of tools and machinery, the performance of work on electrical and electronic equipment, the handling, stowage, and disposal of radioactive and cathode-ray tubes, and the operation of fire control systems.

15-34. Assume that when you replace a defective grounded plug on a 3-conductor cord connected to a portable drill, you fail to connect the ground wire to the ground contact of the plug. What is the likely result of this error?

1. Damage to the 3-conductor wire
2. Damage to the grounded-type plug
3. Damage to the drill motor
4. Injury to the operator

15-35. Which of the following practices is NOT a prudent safety precaution to observe while working on an energized circuit?

1. Working with only one hand as much as possible
2. Using insulated handtools
3. Bypassing door cut out switches
4. Standing on insulated deck matting

15-36. When a radioactive tube is broken in the work space, which of the following actions should be taken?

1. Isolate the area
2. Follow procedures in NAVMED P-5055
3. Notify cognizant authority
4. All of the above

Learning Objective: Identify the functions and uses of electronic and nonelectronic multimeters.

IN ANSWERING QUESTIONS 15-37 THROUGH 15-39, REFER TO FIGURE 16-12 OF THE TEXT.

15-37. The ohmmeter section of the multimeter receives power to activate the meter movement from what source?

1. An external battery
2. The circuit being tested
3. An internal battery
4. A generator

15-38. While using the illustrated multimeter and a special high voltage probe to make measurements in a +4,500-volt circuit, the operator observes that the neon lamp in the probe is lighted. This is an indication of what condition?

1. The voltage at the test point exceeds the range selected
2. The probe is connected to a dangerously high voltage
3. The 100-megohm multiplier is in the circuit and the scale reading is not reliable
4. The 100-megohm multiplier is not in the circuit and the scale reading must be multiplied by a factor of 10

15-39. What procedure do you use to adjust an ohmmeter to ensure an accurate reading?

1. Connect it to a low-voltage source and adjust the rheostat until the meter reads zero
2. Connect it to a low-voltage source, adjust the rheostat until the meter reads maximum, and then short the test leads together
3. Short the test leads together and adjust the rheostat until the meter reads zero
4. Short the test leads together and adjust the rheostat until the meter is deflected full scale

15-40. The loading effect of a vtvm is small compared to that of a multimeter because of the

1. high capacitance in the vtvm's vacuum tube rectifier
2. low capacitance in the vtvm's metallic-oxide rectifier
3. high input impedance of the vtvm's input circuit
4. low input impedance of the vtvm's input circuit

IN ANSWERING QUESTIONS 15-41 AND 15-42, REFER TO FIGURE 16-13 OF THE TEXT.

15-41. What is the smallest amount of d.c. current that can be measured with the illustrated vtvm?

1. 0.02 microamperes
2. 0.20 microamperes
3. 2.00 microamperes
4. 20.0 microamperes

15-42. What type of measurement made with the vtvm does not use the bridge circuit?

1. D.c. voltage
2. Resistance
3. D.c. current
4. A.c. voltage

15-43. How is the differential voltmeter used to determine the value of an unknown voltage?

1. A switching arrangement permits switching between the unknown voltage and test-set voltage so that identical meter deflections can be observed
2. A switching arrangement permits the unknown voltage to be read on one side of a center-zero meter and test-set balancing voltage to be read on the other side
3. The unknown voltage is compared to an adjustable reference voltage supplied by the voltmeter and is read from the voltage dials
4. The unknown voltage is balanced out by voltage supplied by the test set, and the value of test-set voltage thus required is read from a meter

15-44. What instrument measures resistances of many megohms by applying high voltage to the component under test and measuring its leakage current?

1. A Megger
2. A multimeter
3. A megohmmeter
4. A volt-ohm-milliammeter

15-45. What reading will occur if a Megger is used to read a resistance that exceeds its range?

1. 0 ohms
2. Midscale
3. 1000 megohms
4. Infinity

Learning Objective: Identify the procedures for testing circuits for continuity, grounds and shorts, voltage, and resistance.

15-46. A continuity test is performed on a piece of electronic equipment to discover what type of defect?

1. Low voltage
2. Weak tubes
3. Changes in component values
4. Open circuits

15-47. Which of the following meters is recommended for continuity tests?

1. An ohmmeter
2. A Megger
3. A voltmeter
4. An ammeter

IN ANSWERING QUESTIONS 15-48 THROUGH 15-50, REFER TO FIGURE 16-16 OF THE TEXT.

15-48. What resistance does the ohmmeter indicate when connected as shown?

1. 0 ohms
2. Maximum
3. Midscale
4. 100 ohms

15-49. The conductors between plug 1 and plug 2 can be tested for grounds by connecting one meter probe to ground and the other probe to the conductors
______(a)______ with
individually, collectively
the jumper ______(b)______
connected, removed.

1. (a) individually
   (b) connected
2. (a) individually
   (b) removed
3. (a) collectively
   (b) connected
4. (a) collectively
   (b) removed

15-50. Assume that conductors A and B are shorted together between plug 1 and plug 2. To what points must an ohmmeter's probes be attached in order to detect the short?

1. Between conductor A and ground
2. Between conductor B and ground
3. Between conductor A and conductor B
4. Between conductor A and the jumper

15-51. What precaution must you observe before you test circuit voltages with a voltmeter?

1. Set the meter to the lowest range
2. Remove the suspected component from the circuit
3. See if the voltage coming from the power source is correct
4. Check current flow through the circuit with an ammeter

15-52. Why is it important to set the voltmeter on its highest range scale before starting a measurement?

1. To increase the sensitivity of the measurement
2. To protect the equipment being tested
3. To systematize the procedure
4. To keep the meter from being overloaded

15-53. If set to the 100-volt range and if its sensitivity is 2,000 ohms per volt, what is the resistance of a voltmeter?

1. 50,000 ohms
2. 100,000 ohms
3. 200,000 ohms
4. 300,000 ohms

15-54. The low resistance range of an ohmmeter is used for checking which of the following conditions?

1. Leakage resistance of capacitors
2. Leakage resistance of cables
3. Circuit continuity
4. Grounds

QUESTION 15-55 AND 15-56 ARE TO BE JUDGED TRUE OR FALSE.

15-55. When a resistor is connected across the winding of a transformer, a direct resistance reading of the resistor would be invalid.

1. True
2. False

15-56. A low internal resistance voltmeter shunts the circuit being measured and results in accurate readings.

1. True
2. False

Assignment 16

General Maintenance (continued); Administration

Textbook Assignment: FTG 3&2, NAVEDTRA 10207-B; pages 16-27 through 17-10

Learning Objective: Identify the methods of testing electron tubes and transistors. Describe the operation of a tube tester and a transistor tester.

16-1. What is the simplest method of determining the condition of a tube?

1. Emission measurement
2. Transconductance test
3. Amplification comparison
4. Frequency response

16-2. A transconductance test tests what characteristic of a tube?

1. Total emission volume
2. Total power out
3. A.c. amplification ability
4. Frequency response

16-3. What is the best method of testing high-power tubes?

1. Emission
2. Transconductance
3. Frequency response
4. Substitution

IN ANSWERING QUESTIONS 16-4 THROUGH 16-10, REFER TO FIGURE 16-17 OF THE TEXT.

16-4. What total number of scales is on the meter?

1. One
2. Two
3. Three
4. Four

16-5. The filament voltage of the tube under test can be reduced ten percent by initiating what action?

1. Depressing the CATH ACT (S302D) pushbutton
2. Tuning the SIGNAL CAL (R152 and R155) controls
3. Balancing the Gm bridge circuit
4. Depressing the pushbutton S302C

16-6. Grid-to-cathode shorts at a sensitivity much higher than normal are checked by depressing what pushbutton?

1. S302E
2. S302D
3. S302C
4. S302B

16-7. What is the first step in using the tube tester for the first time?

1. Insert the tube to be tested
2. Calibrate the tester using the calibration test cards
3. Adjust the filament voltages
4. Depress the CATH ACT pushbutton

16-8. When the card switch is actuated, the tube under test is automatically subjected to which of the following tests?

1. Interelement short and QUALITY
2. Heater-to-cathode leakage and emission
3. Interelement short and heater-to-cathode leakage
4. QUALITY and GAS

16-9. During the QUALITY test, what scale is read on meter M301?

1. One
2. Two
3. Three
4. Four

16-10. When a dual tube has identical sections that may be tested with the same card, how will the tube tester indicate that this situation exists?

1. DS203 will light
2. The number 2 pushbutton will also depress when the number 3 pushbutton is depressed
3. DS204 will light
4. The meter will deflect to mid-scale

16-11. The condition of a transistor can be determined by checking what two performance characteristics?

1. Frequency response and gain
2. Current gain and reverse current
3. Reverse current and interelectrode capacitance
4. Interelectrode capacitance and frequency response

IN ANSWERING QUESTIONS 16-12 THROUGH 16-16, REFER TO FIGURE 16-19 OF THE TEXT.

16-12. When the POLARITY switch is in the OFF position, what should the meter pointer indicate?

1. Full scale deflection
2. Mid scale deflection
3. Zero deflection
4. Battery condition

16-13. In order to make an accurate measurement, a total of how much resistance must exist between E-B, C-B, and C-E?

1. 100 ohms
2. 200 ohms
3. 300 ohms
4. 400 ohms

16-14. During the initial setup for testing a transistor, the test set RANGE switch should be set to what position?

1. 0.01
2. 0.1
3. 1.0
4. 10.0

16-15. With the proper amount of emitter to base resistance present, what is the accuracy of the BETA X1, X10 range?

1. ± 1.5 percent
2. ± 15 percent
3. ± 3.0 percent
4. ± 30 percent

16-16. When diodes are tested, what is indicated by a meter reading less than midscale?

1. The diode is good
2. The diode is shorted
3. The diode is open
4. Either 2 or 3 above

16-17. What is the maximum ohmmeter current level that is safe for use on transistor circuits?

1. 1 milliampere
2. 0.1 ampere
3. 1.0 ampere
4. 0.1 milliampere

Learning Objective: Identify the functions of the major sections of an oscilloscope.

IN ANSWERING QUESTIONS 16-18 THROUGH 16-23, REFER TO FIGURE 16-20 OF THE TEXT.

16-18. What is the principal use of the oscilloscope?

1. Visual examination of waveforms of voltages or current
2. Location of radio interference
3. Measurement of UHF and microwave energy
4. Measurement of frequency response in audio equipment

16-19. The horizontal axis of an oscilloscope represents what waveform characteristic?

1. Amplitude
2. Intensity
3. Elapsed time
4. Quantity

16-20. The vertical axis of an oscilloscope represents what waveform characteristic?

1. Amplitude
2. Quantity
3. Intensity
4. Each of the above

16-21. The oscilloscope is capable of performing which of the following measurements on a given waveform?

1. The rise time
2. The magnitude
3. The time difference between two points
4. Each of the above

16-22. The display of a large signal that extends off the face of the oscilloscope may be reduced to a usable amplitude by use of which of the following controls?

1. Volts/cm calibrated attenuator
2. Horizontal position knob
3. Vertical position knob
4. Sweep mode control

16-23. The input to an oscilloscope is normally applied to what circuit?

1. The horizontal deflection
2. The vertical deflection
3. The time delay amplifier
4. The intensity amplifier

16-24. The time required for the dot to return to the point of origin is identified by what term?

1. Rise time
2. Negative deflection
3. Flyback time
4. Positive deflection

16-25. The voltage range of an oscilloscope can be extended by the use of what type of probe?

1. A direct
2. An attenuator
3. A high voltage direct
4. An amplifier

16-26. The perception of the dot moving across the oscilloscope face as a solid line is caused by what property of the oscilloscope?

1. Persistence
2. Synchronization frequency
3. Signal frequency
4. Intensity

16-27. The waveform on the face of the oscilloscope remains stationary through the synchronization of what two signals?

1. The crt grid voltage and the horizontal sweep voltage
2. The crt grid voltage and the vertical sweep waveform
3. The horizontal sweep voltage and the intensity voltage
4. The horizontal sweep voltage and the vertical sweep waveform

16-28. The oscilloscope waveform presentation is a measure of what signal voltage value?

1. Rms
2. Peak-to-peak
3. .707 of peak-to-peak
4. .707 of rms

16-29. The peak-to-peak voltage value can be converted directly to the rms value if it is multiplied by what constant?

1. .707
2. 2
3. .3535
4. 7.07

16-30. The number of input signal cycles displayed on an oscilloscope has a directly proportional relationship to the ______(a)______
frequency, amplitude
of the ______(b)______ sweep
horizontal, vertical
signal.

1. (a) frequency (b) horizontal
2. (a) amplitude (b) horizontal
3. (a) frequency (b) vertical
4. (a) amplitude (b) vertical

Learning Objective: Identify the operational and functional characteristics of signal generators.

16-31. The output of a signal generator is normally used for what purpose(s)?

1. To supply plate voltage to electronic equipment
2. To test, align or troubleshoot electronic equipment
3. To produce standard sources of d.c. energy
4. All of the above

16-32. Voltage amplitude and impedance values are controlled in many signal generators by

1. calibrated capacitors
2. vacuum tubes
3. attenuators
4. variable resistors

16-33. How is the output frequency of a beat-frequency type video signal generator produced?

1. By mixing the signals of a fixed and a variable rf oscillator
2. By mixing the signals of two fixed rf oscillators
3. By mixing the signals of two variable rf oscillators
4. By mixing the output of two audio-frequency oscillators

16-34. The frequency of an audio-signal generator can be determined by which of the following devices?

1. An attenuator
2. A resistance network
3. A resistance-capacitance network
4. A resistance-diode network

16-35. The output of the amplifier section of a audio signal generator is often coupled to the output control by which of the following methods?

1. An attenuator
2. A transformer
3. An RC network
4. An RL network

16-36. A modulation signal for the output of the oscillator stage of an rf signal generator may be produced from which of the following sources?

1. A plug-in module
2. An internal modulator
3. An external signal
4. Both 2 and 3 above

16-37. In low-frequency signal generators, the frequency ranges are changed by changing what component in the resonant circuit?

1. The capacitor
2. The coil
3. The resistor
4. The oscillator tube

16-38. The rf output of a signal generator can be modulated by which of the following signal types?

1. Sine wave
2. Square wave
3. Variable duration pulses
4. Each of the above

16-39. The output level of a signal generator is controlled by what type of device?

1. An attenuator
2. A potentiometer
3. A rheostat
4. A variable capacitor

16-40. The overall variation about the center frequency in frequency modulation is known by what term?

1. Degree of modulation
2. Frequency swing
3. Output swing
4. Frequency percentage

16-41. Which of the following sources may be used to produce a frequency modulation signal for the output of the oscillator stage of an rf signal generator?

1. An external source
2. A vibrating plate tuned capacitor
3. A reactance tube
4. Each of the above

Learning Objective: Identify the major functions and operational characteristics of electronic counters.

16-42. An electronic counter is capable of performing which of the following functions?

1. Frequency modulation
2. Amplitude modulation
3. Cycle period measurement
4. Voltage variation measurement

16-43. An electronic counter is capable of dividing the frequency of an input signal by what maximum factor?

1. 10
2. 10^2
3. 10^8
4. 10^{12}

16-44. An rf oscillator plug-in module in the electronic counter provides an output signal of what frequency?

1. 1 MHz
2. 2 MHz
3. 3 MHz
4. 4 MHz

16-45. During frequency ratio measurements, what function, if any, does the rf oscillator in the electronic counter perform?

1. It produces a beat frequency
2. It provides comparison frequencies
3. It modulates the input signal
4. None

16-46. The frequency converter plug-in in an electronic counter allows frequency measurements up to what maximum value?

1. 10 MHz
2. 50 MHz
3. 500 MHz
4. 5 GHz

16-47. Measurement with an electronic counter is dependent upon the availability of what two signals?

1. Count and gate control
2. Count and frequency control
3. Period and oscillator
4. Converter and gate control

IN ANSWERING QUESTIONS 16-48 THROUGH 16-50, REFER TO FIGURE 16-30 IN THE TEXT.

16-48. The timing signals to the functional sections of the basic counter are supplied by what unit?

1. The frequency converter
2. The 10 MHz and 1 MHz multiplier
3. The scaler
4. The cycle control

16-49. The length of time the count decades count the count signal is determined by what unit?

1. The cycle control
2. The count control
3. The gate control
4. The scaler

16-50. All the signals necessary to display the measurement results on the readout are provided by what unit?

1. The cycle control
2. The count control
3. The gate control
4. The 10 MHz and 1 MHz multiplier

Learning Objective: Identify the major concepts involved in the administration of fire control systems including reports, records, publications and supply procedures.

16-51. The identification of all the units and subunits within a specific piece of equipment, such as a radar set, is used to aid the establishment of which of the following standards?

1. Operation
2. Performance
3. Maintenance
4. Each of the above

16-52. All publications formerly published by the Bureau of Ordnance are now controlled by what Navy command?

1. NAVSEA
2. NAVMAT
3. ORDSYSCOM
4. NMPC

16-53. Directives containing information of a one-time nature and provisions for their own cancellations are called

1. Notices
2. Bulletins
3. Instructions
4. Specifications

16-54. Which of the following elements is used in the identifier of an Instruction but not in that of a Notice?

1. Type of release
2. Consecutive number
3. Subject classification number
4. Originator's authorization abbreviation

16-55. What does the numeral 3 in the NAVSEA Instruction 8260.3 represent?

1. Type of equipment
2. Number of instructions issued that deal with the subject area
3. Priority of the directive
4. Number of subject areas covered by the directive

16-56. The available instructions concerning the maintenance of radar antennas can be found in the latest revision of what publication?

1. NAVORD OP 0
2. NAVORD OP 3000
3. SECNAVINST 5215
4. NAVPUBINST 5215

16-57. Which of the following ordnance publications deals with the effective use of specific ordnance equipment?

1. Equipment OPs
2. General OPs
3. Instructions
4. Notices

16-58. Your leading petty officer assigns you to work on the Weapon Direction Equipment Mk 4 Mod 0. To which publication do you refer for the number of the OP that pertains to this equipment?

1. OP 0
2. Cog 1 Index
3. OD 9398
4. NAVPUBINST 5215.4B

16-59. The listing of reports that must be submitted by your ship may be found in what publication?

1. NAVSEA 5215 (Series)
2. Type Commander's Instruction 5213 (Series)
3. OP 0
4. OP 3000

16-60. Which of the following alterations to a ship affect its military characteristics through changes to ordnance?

1. SHIPALTs
2. NAVALTs
3. ORDALTs
4. NAVALT ORDALTs

16-61. You have accomplished an ORDALT on a director, and it is a year before your ship is scheduled for the next yard overhaul period. On which form should the report of this ORDALT accomplishment be made?

1. Weapons Systems Component Failure Report, NAVORD Form 8000/13
2. Ship Armament Inventory List (SAIL), NAVORD Form 8000/1
3. ORDALT Accomplishment Requirement (OAR) NAVORD Form 8000/3
4. Ship Armament Inventory List (SAIL) Change Report, NAVORD Form 8000/2

16-62. The ORDALT Accomplishment Requirement (OAR) list has been received aboard your ship. Under what condition must information concerning the ORDALTs listed in this form be supplied to the overhaul activity and NAVSEA?

1. When the material is on board
2. When the material is on order but not on board
3. When accomplishment by ship's force is planned prior to completion of overhaul period
4. Each of the above

16-63. Which type of change is used by NAVSEA to disseminate to the fleet urgent information that concerns hazardous conditions?

1. CH
2. MC
3. ACN
4. CH or ACN

16-64. What type of change is used to issue formal replacement pages to cover configuration changes (ORDALTs and SHIPALTs)?

1. ACN
2. FCH
3. MC
4. CH

16-65. Data and instructions pertaining to classes of installed machinery and equipment are contained in which of the following publications?

1. Naval Ship's Technical Manual
2. Electronics Installation and Maintenance Books (EIMB)
3. OP-3000
4. Ship's Plan Index

16-66. The basic instructions on classified matters are published by what command?

1. Department of the Navy
2. Department of Defense
3. NAVSEA
4. NAVSHIPSYSCOM

16-67. A list of special tools required to service a particular component are found in which of the following publications?

1. Naval Ship's Technical Manual
2. Electronic Installation and Maintenance Book (EIMB)
3. Ordnance Drawings
4. Ship's Plan Index

16-68. Equipments, components and repair parts needed to operate and maintain your ship are listed in what publication?

1. COSAL
2. Federal Supply Catalog
3. IPB
4. SPCC

16-69. The manufacturer's nameplate information usually includes which of the following information?

1. Manufacturer's name
2. Model number
3. Voltage
4. All of the above

16-70. The model of a certain type of ordnance equipment is identified by what type of number?

1. Identifying
2. Mark
3. Modification
4. Piece

16-71. When should "mandatory turn-in" items be returned to the supply department?

1. After cannibalizing necessary components
2. As soon as practicable
3. Before a new part may be ordered
4. Immediately upon ordering a new part

IN ANSWERING QUESTIONS 16-72 THROUGH 16-74, REFER TO FIGURE 17-1 OF THE TEXT.

TO ANSWER QUESTIONS 16-72 THROUGH 16-74, SELECT FROM COLUMN B THE TYPE OF EQUIPMENT THAT IS INDICATED IN COLUMN A.

16-72.	AN/SPW-2B	1. Fire control radar
16-73.	AN/SPQ-5	2. Remote control radar
16-74.	AN/SPG-55	3. Special purpose radar
		4. Telemetering

COURSE DISENROLLMENT

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8	☐	☐	☐	☐	_____	33	☐	☐	☐	☐	_____	58	☐	☐	☐	☐	_____
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18	☐	☐	☐	☐	_____	43	☐	☐	☐	☐	_____	68	☐	☐	☐	☐	_____
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PRINT OR TYPE

NRCC FIRE CONTROL TECHNICIAN G 3 & 2
NAVEDTRA 10207-B

NAME ______________________________ **ADDRESS** ______________________________
Last First Middle Street/Ship/Unit/Division, etc.

____
City or FPO State Zip

RANK/RATE ________ **SOC. SEC. NO.** ______________ **DESIGNATOR** ________ **ASSIGNMENT NO.** ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ______________ DATE MAILED ________

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PRINT OR TYPE

NRCC FIRE CONTROL TECHNICIAN G 3 & 2
NAVEDTRA 10207-B

NAME ______________________ ADDRESS ______________________
Last First Middle Street/Ship/Unit/Division, etc.

____
City or FPO State Zip

RANK/RATE ________ SOC. SEC. NO. ______________________ DESIGNATOR ________ ASSIGNMENT NO. ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ______________ DATE MAILED ________

SCORE ☐

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2	☐	☐	☐	☐	_____	27	☐	☐	☐	☐	_____	52	☐	☐	☐	☐	_____
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PRINT OR TYPE

NRCC FIRE CONTROL TECHNICIAN G 3 & 2
NAVEDTRA 10207-B

NAME ________________________________ ADDRESS ________________________________
Last First Middle Street/Ship/Unit/Division, etc.

____
City or FPO State Zip

RANK/RATE ________ SOC. SEC. NO. ________________ DESIGNATOR ________ ASSIGNMENT NO. ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ________________ DATE MAILED ________

SCORE

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PRINT OR TYPE

NRCC FIRE CONTROL TECHNICIAN G 3 & 2
NAVEDTRA 10207-B

NAME ______________________________ ADDRESS ______________________________
Last First Middle Street/Ship/Unit/Division, etc.

City or FPO State Zip

RANK/RATE ________ SOC. SEC. NO. ________________ DESIGNATOR ________ ASSIGNMENT NO. ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ________________ DATE MAILED ________

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PRINT OR TYPE

NRCC FIRE CONTROL TECHNICIAN G 3 & 2
NAVEDTRA 10207-B

NAME ______________________________ ADDRESS ______________________________
Last First Middle Street/Ship/Unit/Division, etc.

City or FPO State Zip

RANK/RATE ________ SOC. SEC. NO. ____________________ DESIGNATOR ________ ASSIGNMENT NO. ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ____________ DATE MAILED ________

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PRINT OR TYPE

NRCC FIRE CONTROL TECHNICIAN G 3 & 2
NAVEDTRA 10207-B

NAME ____________________ ADDRESS ____________________
Last First Middle — Street/Ship/Unit/Division, etc.

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City or FPO State Zip

RANK/RATE ________ SOC. SEC. NO. ____________________ DESIGNATOR ________ ASSIGNMENT NO. ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ____________ DATE MAILED ________

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NRCC FIRE CONTROL TECHNICIAN G 3 & 2
NAVEDTRA 10207-B

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☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ________________ DATE MAILED ________

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PRINT OR TYPE

NRCC FIRE CONTROL TECHNICIAN G 3 & 2
NAVEDTRA 10207-B

NAME ____________________ ADDRESS ____________________
Last First Middle Street/Ship/Unit/Division, etc.

City or FPO State Zip

RANK/RATE ________ SOC. SEC. NO. ____________ DESIGNATOR ________ ASSIGNMENT NO. ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ____________ DATE MAILED ________

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PRINT OR TYPE

NRCC FIRE CONTROL TECHNICIAN G 3 & 2
NAVEDTRA 10207-B

NAME ______________________________ ADDRESS ______________________________
Last First Middle Street/Ship/Unit/Division, etc.

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City or FPO State Zip

RANK/RATE ________ SOC. SEC. NO. ____________________ DESIGNATOR ________ ASSIGNMENT NO. ________

☐ USN ☐ USNR ☐ ACTIVE ☐ INACTIVE OTHER (Specify) ________________ DATE MAILED ________

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NRCC FIRE CONTROL TECHNICIAN G 3 & 2
NAVEDTRA 10207-B

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PRINT OR TYPE

NRCC FIRE CONTROL TECHNICIAN G 3 & 2
NAVEDTRA 10207-B

NAME ______________________________ ADDRESS ______________________________
Last First Middle Street/Ship/Unit/Division, etc.

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City or FPO State Zip

RANK/RATE ________ SOC. SEC. NO. ______________________ DESIGNATOR ________ ASSIGNMENT NO. ________

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